FIG. **4** is a perspective view of a carbon dioxide SAW sensor for mounting in the trunk lid for monitoring the inside of the trunk for detecting trapped children or animals.

FIG. **4**A is a detailed view of the SAW carbon dioxide sensor of FIG. **4**.

FIG. **5** is a schematic illustration of a generalized component with several signals being emitted and transmitted along a variety of paths, sensed by a variety of sensors and analyzed by the diagnostic module in accordance with the invention and for use in a method in accordance with the invention.

FIG. **6** is a schematic of one pattern recognition methodology known as a neural network which may be used in a method in accordance with the invention.

FIG. **7** is a schematic of a vehicle with several components and several sensors and a total vehicle diagnostic system in accordance with the invention utilizing a diagnostic module in accordance with the invention and which may be used in a method in accordance with the invention.

FIG. **8** is a flow diagram of information flowing from various sensors onto the vehicle data bus and thereby into the diagnostic module in accordance with the invention with outputs to a display for notifying the driver, and to the vehicle cellular phone for notifying another person, of a potential component failure.

FIG. **9** is a flow chart of the methods for automatically monitoring a vehicular component in accordance with the invention.

FIG. **10** is a schematic illustration of the components used in the methods for automatically monitoring a vehicular component.

FIG. **11** is a schematic of a vehicle with several accelerometers and/or gyroscopes at preferred locations in the vehicle.

FIG. **12** is a schematic view of overall telematics system in accordance with the invention.

FIG. **13**A is a partial cutaway view of a tire pressure monitor using an absolute pressure measuring SAW device.

FIG. **13**B is a partial cutaway view of a tire pressure monitor using a differential pressure measuring SAW device.

FIG. **14** is a partial cutaway view of an interior SAW tire temperature and pressure monitor mounted onto and below the valve stem.

FIG. **14**A is a sectioned view of the SAW tire pressure and temperature monitor of FIG. **14** incorporating an absolute pressure SAW device.

FIG. **14**B is a sectioned view of the SAW tire pressure and temperature monitor of FIG. **14** incorporating a differential pressure SAW device.

FIG. **15** is a view of an accelerometer-based tire monitor also incorporating a SAW pressure and temperature monitor and cemented to the interior of the tire opposite the tread.

FIG. **15**A is a view of an accelerometer-based tire monitor also incorporating a SAW pressure and temperature monitor and inserted into the tire opposite the tread during manufacture.

FIG. **16** is a detailed view of a polymer on SAW pressure sensor.

FIG. **16**A is a view of a SAW temperature and pressure monitor on a single SAW device.

FIG. **16**B is a view of an alternate design of a SAW temperature and pressure monitor on a single SAW device.

FIG. **17** is a perspective view of a SAW temperature sensor.

FIG. **17**A is a perspective view of a device that can provide two measurements of temperature or one of temperature and another of some other physical or chemical property such as pressure or chemical concentration.

FIG. **17**B is a top view of an alternate SAW device capable of determining two physical or chemical properties such as pressure and temperature.

FIGS. **18** and **18**A are views of a prior art SAW accelerometer that can be used for the tire monitor assembly of FIG. **15**.

FIGS. **19**A, **19**B, **19**C, **19**D and **19**E are views of occupant seat weight sensors using a slot spanning SAW strain gage and other strain concentrating designs.

FIG. **20**A is a view of a view of a SAW switch sensor for mounting on or within a surface such as a vehicle armrest.

FIG. **20**B is a detailed perspective view of the device of FIG. **20**A with the force-transmitting member rendered transparent.

FIG. **20**C is a detailed perspective view of an alternate SAW device for use in FIGS. **20**A and **20**B showing the use of one of two possible switches, one that activates the SAW and the other that suppresses the SAW.

FIG. **21**A is a detailed perspective view of a polymer and mass on SAW accelerometer for use in crash sensors, vehicle navigation, etc.

FIG. **21**B is a detailed perspective view of a normal mass on SAW accelerometer for use in crash sensors, vehicle navigation, etc.

FIG. **22** is a view of a prior art SAW gyroscope that can be used with this invention.

FIGS. **23**A, **23**B and **23**C are a block diagrams of three interrogators that can be used with this invention to interrogate several different devices.

FIG. **24** is a perspective view of a SAW antenna system adapted for mounting underneath a vehicle and for communicating with the four mounted tires.

FIG. **24**A is a detail view of an antenna system for use in the system of FIG. **24**.

FIG. **25** is an overhead view of a roadway with vehicles and a SAW road temperature and humidity monitoring sensor.

FIG. **25**A is a detail drawing of the monitoring sensor of FIG. **25**.

FIG. **26** is a perspective view of a SAW system for locating a vehicle on a roadway, and on the earth surface if accurate maps are available. It also illustrates the use of a SAW transponder in the license plate for the location of preceding vehicles and preventing rear end impacts.

FIG. **27** is a partial cutaway view of a section of a fluid reservoir with a SAW fluid pressure and temperature sensor for monitoring oil, water, or other fluid pressure.

FIG. **28** is a perspective view of a vehicle suspension system with SAW load sensors.

FIG. **28**A is a cross section detail view of a vehicle spring and shock absorber system with a SAW torque sensor system mounted for measuring the stress in the vehicle spring of the suspension system of FIG. **28**.

FIG. **28**B is a detail view of a SAW torque sensor and shaft compression sensor arrangement for use with the arrangement of FIG. **28**.

FIG. **29** is a cutaway view of a vehicle showing possible mounting locations for vehicle interior temperature, humidity, carbon dioxide, carbon monoxide, alcohol or other chemical or physical property measuring sensors.

FIG. **30**A is a perspective view of a SAW tilt sensor using four SAW assemblies for tilt measurement and one for temperature.

FIG. **30**B is a top view of a SAW tilt sensor using three SAW assemblies for tilt measurement each one of which can also measure temperature.

FIG. **31** is a perspective exploded view of a SAW crash sensor for sensing frontal, side or rear crashes.

FIG. **32**A is a partial cutaway view of a piezoelectric generator and tire monitor using PVDF film.

FIG. **32**B is a cutaway view of the PVDF sensor of FIG. **32**A.

FIG. **33** is a perspective view with portions cutaway of a SAW based vehicle gas gage.

FIG. **33**A is a top detailed view of a SAW pressure and temperature monitor for use in the system of FIG. **33**.

FIG. **34** is a partial cutaway view of a vehicle drives wearing a seatbelt with SAW force sensors.

FIG. **35** is an alternate arrangement of a SAW tire pressure and temperature monitor installed in the wheel rim facing inside.

FIG. **36**A is a schematic of a prior art deployment scheme for an airbag module.

FIG. **36**B is a schematic of a deployment scheme for an airbag module in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

As noted above, the invention relates generally to telematics and the transmission of information from a vehicle to one or more remote sites which can react to the position or status of the vehicle or occupant(s) therein.

Initially, sensing of the occupancy of the vehicle and the optional transmission of this information, which may include images, to remote locations will be discussed. This entails obtaining information from various sensors about the occupants in the passenger compartment of the vehicle, e.g., the number of occupants, their type and their motion, if any. Thereafter, a discussion of general vehicle diagnostic methods will be discussed with the diagnosis being transmittable via a communications device to the remote locations. Finally, an extensive discussion of various sensors for use on the vehicle to sense different operating parameters and conditions of the vehicle is provided. All of the sensors discussed herein can be coupled to a communications device enabling transmission of data, signals and/or images to the remote locations, and reception of the same from the remote locations.

Referring to the accompanying drawings wherein the same reference numerals refer to the same or similar elements, FIG. **1** is a side view, with parts cutaway and removed of a vehicle showing the passenger compartment containing a rear facing child seat **610** on a front passenger seat **620** and one mounting location for a first embodiment of a vehicle interior monitoring system in accordance with the invention. The interior monitoring system is capable of detecting the presence of an object, determining the type of object, determining the location of the object, and/or determining another property or characteristic of the object. A property of the object could be the orientation of a child seat, the velocity of an adult and the like. For example, the vehicle interior monitoring system can determine that an object is present on the seat, that the object is a child seat and that the child seat is rear-facing. The vehicle interior monitoring system could also determine that the object is an adult, that he is drunk and that he is out of position relative to the airbag.

In this embodiment, six transducers **631**, **632**, **633**, **640**, **641** and **646** are used, although any number of transducers may be used. Each transducer **631**, **632**, **633**, **640**, **641**, **646** may comprise only a transmitter which transmits energy, waves or radiation, only a receiver which receives energy, waves or radiation, both a transmitter and a receiver capable of transmitting and receiving energy, waves or radiation, an electric field sensor, a capacitive sensor, or a self-tuning antenna-based sensor, weight sensor, chemical sensor, motion sensor or vibration sensor, for example.

Such transducers or receivers may be of the type which emit or receive a continuous signal, a time varying signal (such as a capacitor or electric field sensor) or a spacial varying signal such as in a scanning system. One particular type of radiation-receiving receiver for use in the invention is a receiver capable of receiving electromagnetic waves.

When ultrasonic energy is used, transducer **632** can be used as a transmitter and transducers **631**,**633** as receivers. Naturally, other combinations can be used such as where all transducers are transceivers (transmitters and receivers). For example, transducer **632** can be constructed to transmit ultrasonic energy toward the front passenger seat, which is modified, in this case by the occupying item of the passenger seat, i.e., the rear facing child seat **610**, and the modified waves are received by the transducers **631** and **633**, for example. A more common arrangement is where transducers **631**, **632** and **633** are all transceivers. Modification of the ultrasonic energy may constitute reflection of the ultrasonic energy as the ultrasonic energy is reflected back by the occupying item of the seat. The waves received by transducers **631** and **633** vary with time depending on the shape of the object occupying the passenger seat, in this case the rear facing child seat **610**. Each object will reflect back waves having a different pattern. Also, the pattern of waves received by transducer **631** will differ from the pattern received by transducer **633** in view of its different mounting location. This difference generally permits the determination of location of the reflecting surface (i.e., the rear facing child seat **610**) through triangulation. Through the use of two transducers **631**,**633**, a sort of stereographic image is received by the two transducers and recorded for analysis by processor **601**, which is coupled to the transducers **631**,**632**, **633**. This image will differ for each object that is placed on the vehicle seat and it will also change for each position of a particular object and for each position of the vehicle seat. Elements **631**, **632**, **633**, although described as transducers, are representative of any type of component used in a wave-based analysis technique.

Mention is made above of the use of wave-type sensors as the transducers **631**, **632**, **633** as well as electric field sensors. Electric field sensors and wave sensors are essentially the same from the point of view of sensing the presence of an occupant in a vehicle. In both cases, a time varying electric field is disturbed or modified by the presence of the occupant. At high frequencies in the visual, infrared and high frequency radio wave region, the sensor is based on its capability to sense change of wave characteristics of the electromagnetic field, such as amplitude, phase or frequency. As the frequency drops, other characteristics of the field are measured. At still lower frequencies, the occupant's dielectric properties modify parameters of the reactive electric field in the occupied space between/near the plates of a capacitor. In this latter case, the sensor senses the change in charge distribution on the capacitor plates by measuring, for example, the current wave magnitude or phase in the electric circuit that drives the capacitor. These measured parameters are directly connected with parameters

of the displacement current in the occupied space. In all cases, the presence of the occupant reflects, absorbs or modifies the waves or variations in the electric field in the space occupied by the occupant. Thus for the purposes of this invention, capacitance, electric field or electromagnetic wave sensors are equivalent and although they are all technically "field" sensors they will be considered as "wave" sensors herein. What follows is a discussion comparing the similarities and differences between two types of field or wave sensors, electromagnetic wave sensors and capacitive sensors as exemplified by Kithil in U.S. Pat. No. 5,702,634.

An electromagnetic field disturbed or emitted by a passenger in the case of an electromagnetic wave sensor, for example, and the electric field sensor of Kithil, for example, are in many ways similar and equivalent for the purposes of this invention. The electromagnetic wave sensor is an actual electromagnetic wave sensor by definition because they sense parameters of a wave, which is a coupled pair of continuously changing electric and magnetic fields. The electric field here is not a static, potential one. It is essentially a dynamic, rotational electric field coupled with a changing magnetic one, that is, an electromagnetic wave. It cannot be produced by a steady distribution of electric charges. It is initially produced by moving electric charges in a transmitter, even if this transmitter is a passenger body for the case of a passive infrared sensor.

In the Kithil sensor, a static electric field is declared as an initial material agent coupling a passenger and a sensor (see Column 5, lines 5–7): "The proximity sensor **12** each function by creating an electrostatic field between oscillator input loop **54** and detector output loop **56**, which is affected by presence of a person near by, as a result of capacitive coupling, . . . "). It is a potential, non-rotational electric field. It is not necessarily coupled with any magnetic field. It is the electric field of a capacitor. It can be produced with a steady distribution of electric charges. Thus, it is not an electromagnetic wave by definition but if the sensor is driven by a varying current, then it produces a quasistatic electric field in the space between/near the plates of the capacitor.

Kithil declares that his capacitance sensor uses a static electric field. Thus, from the consideration above, one can conclude that Kithil's sensor cannot be treated as a wave sensor because there are no actual electromagnetic waves but only a static electric field of the capacitor in the sensor system. However, this is not believed to be the case. The Kithil system could not operate with a true static electric field because a steady system does not carry any information. Therefore, Kithil is forced to use an oscillator, causing an alternate current in the capacitor and a reactive quasistatic electric field in the space between the capacitor plates, and a detector to reveal an informative change of the sensor capacitance caused by the presence of an occupant (see FIG. **7** and its description). In this case, the system becomes a "wave sensor" in the sense that it starts generating actual time-varying electric field that certainly originates electromagnetic waves according to the definition above. That is, Kithil's sensor can be treated as a wave sensor regardless of the shape of the electric field that it creates, a beam or a spread shape.

As follows from the Kithil patent, the capacitor sensor is likely a parametric system where the capacitance of the sensor is controlled by influence of the passenger body. This influence is transferred by means of the near electromagnetic field (i.e., the wave-like process) coupling the capacitor electrodes and the body. It is important to note that the same influence takes place with a real static electric field also, that is in absence of any wave phenomenon. This would be a situation if there were no oscillator in Kithil's system. However, such a system is not workable and thus Kithil reverts to a dynamic system using time-varying electric fields.

Thus, although Kithil declares the coupling is due to a static electric field, such a situation is not realized in his system because an alternating electromagnetic field ("quasi-wave") exists in the system due to the oscillator. Thus, his sensor is actually a wave sensor, that is, it is sensitive to a change of a wave field in the vehicle compartment. This change is measured by measuring the change of its capacitance. The capacitance of the sensor system is determined by the configuration of its electrodes, one of which is a human body, that is, the passenger inside of and the part which controls the electrode configuration and hence a sensor parameter, the capacitance.

The physics definition of "wave" from Webster's Encyclopedic Unabridged Dictionary is: "11. *Physics*. A progressive disturbance propagated from point to point in a medium or space without progress or advance of the points themselves, . . . ". In a capacitor, the time that it takes for the disturbance (a change in voltage) to propagate through space, the dielectric and to the opposite plate is generally small and neglected but it is not zero. As the frequency driving the capacitor increases and the distance separating the plates increases, this transmission time as a percentage of the period of oscillation can become significant. Nevertheless, an observer between the plates will see the rise and fall of the electric field much like a person standing in the water of an ocean. The presence of a dielectric body between the plates causes the waves to get bigger as more electrons flow to and from the plates of the capacitor. Thus, an occupant affects the magnitude of these waves which is sensed by the capacitor circuit. Thus, the electromagnetic field is a material agent that carries information about a passenger's position in both Kithil's and a beam-type electromagnetic wave sensor.

For ultrasonic systems, the "image" recorded from each ultrasonic transducer/receiver, is actually a time series of digitized data of the amplitude of the received signal versus time. Since there are two receivers, two time series are obtained which are processed by the processor **601**. The processor **601** may include electronic circuitry and associated, embedded software. Processor **601** constitutes one form of generating means in accordance with the invention which generates information about the occupancy of the passenger compartment based on the waves received by the transducers **631,632,633**.

When different objects are placed on the front passenger seat, the two images from transducers **631,633**, for example, are different but there are also similarities between all images of rear facing child seats, for example, regardless of where on the vehicle seat it is placed and regardless of what company manufactured the child seat. Alternately, there will be similarities between all images of people sitting on the seat regardless of what they are wearing, their age or size. The problem is to find the "rules" which differentiate the images of one type of object from the images of other types of objects, e.g., which differentiate the occupant images from the rear facing child seat images. The similarities of these images for various child seats are frequently not obvious to a person looking at plots of the time series and thus computer algorithms are developed to sort out the various patterns. For a more detailed discussion of pattern recognition see U.S. Pat. No. 5,943,295 to Varga et. al., which is incorporated herein by reference.

The determination of these rules is important to the pattern recognition techniques used in this invention. In

general, three approaches have been useful, artificial intelligence, fuzzy logic and artificial neural networks (including cellular and modular or combination neural networks and support vector machines) (although additional types of pattern recognition techniques may also be used, such as sensor fusion). In some implementations of this invention, such as the determination that there is an object in the path of a closing window as described below, the rules are sufficiently obvious that a trained researcher can sometimes look at the returned signals and devise a simple algorithm to make the required determinations. In others, such as the determination of the presence of a rear facing child seat or of an occupant, artificial neural networks are used to determine the rules. One such set of neural network software for determining the pattern recognition rules is available from the NeuralWare Corporation of Pittsburgh, Pa.

The system used in a preferred implementation of this invention for the determination of the presence of a rear facing child seat, of an occupant or of an empty seat is the artificial neural network. In this case, the network operates on the two returned signals as sensed by transducers **631** and **633**, for example. Through a training session, the system is taught to differentiate between the three cases. This is done by conducting a large number of experiments where all possible child seats are placed in all possible orientations on the front passenger seat. Similarly, a sufficiently large number of experiments are run with human occupants and with boxes, bags of groceries and other objects (both inanimate and animate). Sometimes as many as 1,000,000 such experiments are run before the neural network is sufficiently trained so that it can differentiate among the three cases and output the correct decision with a very high probability. Of course, it must be realized that a neural network can also be trained to differentiate among additional cases, e.g., a forward facing child seat.

Once the network is determined, it is possible to examine the result using tools supplied by NeuralWare or International Scientific Research, for example, to determine the rules that were finally arrived at by the trial and error techniques. In that case, the rules can then be programmed into a microprocessor resulting in a fuzzy logic or other rule based system. Alternately, a neural computer, or cellular neural network, can be used to implement the net directly. In either case, the implementation can be carried out by those skilled in the art of pattern recognition. If a microprocessor is used, a memory device is also required to store the data from the analog to digital converters that digitize the data from the receiving transducers. On the other hand, if a neural network computer is used, the analog signal can be fed directly from the transducers to the neural network input nodes and an intermediate memory is not required. Memory of some type is needed to store the computer programs in the case of the microprocessor system and if the neural computer is used for more than one task, a memory is needed to store the network specific values associated with each task.

Electromagnetic energy based occupant sensors exist that use many portions of the electromagnetic spectrum. A system based on the ultraviolet, visible or infrared portions of the spectrum generally operate with a transmitter and a receiver of reflected radiation. The receiver may be a camera or a photo detector such as a pin or avalanche diode as described in detail in above-referenced patents and patent applications. At other frequencies, the absorption of the electromagnetic energy is primarily and at still other frequencies the capacitance or electric field influencing effects are used. Generally, the human body will reflect, scatter, absorb or transmit electromagnetic energy in various degrees depending on the frequency of the electromagnetic waves. All such occupant sensors are included herein.

In the embodiment wherein electromagnetic energy is used, it is to be appreciated that any portion of the electromagnetic signals that impinges upon, surrounds or involves a body portion of the occupant is at least partially absorbed by the body portion. Sometimes, this is due to the fact that the human body is composed primarily of water, and that electromagnetic energy of certain frequencies is readily absorbed by water. The amount of electromagnetic signal absorption is related to the frequency of the signal, and size or bulk of the body portion that the signal impinges upon. For example, a torso of a human body tends to absorb a greater percentage of electromagnetic energy than a hand of a human body.

Thus, when electromagnetic waves or energy signals are transmitted by a transmitter, the returning waves received by a receiver provide an indication of the absorption of the electromagnetic energy. That is, absorption of electromagnetic energy will vary depending on the presence or absence of a human occupant, the occupant's size, bulk, surface reflectivity, etc. depending on the frequency, so that different signals will be received relating to the degree or extent of absorption by the occupying item on the seat. The receiver will produce a signal representative of the returned waves or energy signals which will thus constitute an absorption signal as it corresponds to the absorption of electromagnetic energy by the occupying item in the seat.

One or more of the transducers **631**, **632**, **633** can also be image-receiving devices, such as cameras, which take images of the interior of the passenger compartment. These images can be transmitted to a remote facility to monitor the passenger compartment or can be stored in a memory device for use in the event of an accident, i.e., to determine the status of the occupants of the vehicle prior to the accident. In this manner, it can be ascertained whether the driver was falling asleep, talking on the phone, etc.

A memory device for storing the images of the passenger compartment, and also for receiving and storing any of the other information, parameters and variables relating to the vehicle or occupancy of the vehicle, may be in the form a standardized "black box" (instead of or in addition to a memory part in a processor **601**). The IEEE Standards Association is currently beginning to develop an international standard for motor vehicle event data recorders. The information stored in the black box and/or memory unit in the processor **601**, can include the images of the interior of the passenger compartment as well as the number of occupants and the health state of the occupants. The black box would preferably be tamper-proof and crash-proof and enable retrieval of the information after a crash.

FIG. **2** shows schematically the interface between a vehicle interior monitoring system in accordance with the invention and the vehicle's cellular or other telematics communication system. An adult occupant **710** is shown sitting on the front passenger seat **720** and four transducers **731**, **732**, **640** and **641** are used to determine the presence (or absence) of the occupant on that seat **720**. One of the transducers **732** in this case acts as both a transmitter and receiver while transducer **731** acts only as a receiver. Alternately, transducer **731** could serve as both a transmitter and receiver or the transmitting function could be alternated between the two devices. Also, in many cases more that two transmitters and receivers are used and in still other cases other types of sensors, such as electric field, capacitance,

self-tuning antennas (collectively represented by **140** and **141**), weight, seatbelt, heartbeat, motion and seat position sensors, are also used in combination with the radiation sensors.

For a general object, transducers **731**, **732**, **140**, **141** can also be used to determine the type of object, determine the location of the object, and/or determine another property or characteristic of the object. A property of the object could be the orientation of a child seat, the velocity of an adult and the like. For example, the transducers **731**, **732**, **140**, **141** can be designed to enable a determination that an object is present on the seat, that the object is a child seat and that the child seat is rear-facing.

The transducers **731** and **732** are attached to the vehicle buried in the A-pillar trim, where their presence can be disguised, and are connected to processor **601** that may also be hidden in the trim as shown (this being a nonlimiting position for the processor **601**). The A-pillar is the roof support pillar that is closest to the front of the vehicle and which, in addition to supporting the roof, also supports the front windshield and the front door. Other mounting locations can also be used. For example, transducers **731**, **732** can be mounted inside the seat (along with or in place of transducers **140** and **141**), in the ceiling of the vehicle, in the B-pillar, in the C-pillar and in the doors. Indeed, the vehicle interior monitoring system in accordance with the invention may comprise a plurality of monitoring units, each arranged to monitor a particular seating location. In this case, for the rear seating locations, transducers might be mounted in the B-pillar or C-pillar or in the rear of the front seat or in the rear side doors. Possible mounting locations for transducers, transmitters, receivers and other occupant sensing devices are disclosed in the above-referenced patent applications and all of these mounting locations are contemplated for use with the transducers described herein.

The cellular phone or other communications system **740** outputs to an antenna **750A**. The transducers **731**, **732**, **140** and **141** in conjunction with the pattern recognition hardware and software, which is implemented in processor **601** and is packaged on a printed circuit board or flex circuit along with the transducers **731** and **732**, determine the presence of an occupant within a few seconds after the vehicle is started, or within a few seconds after the door is closed. Similar systems located to monitor the remaining seats in the vehicle, also determine the presence of occupants at the other seating locations and this result is stored in the computer memory which is part of each monitoring system processor **601**.

Periodically and in particular in the event of an accident, the electronic system associated with the cellular phone system **740** interrogates the various interior monitoring system memories and arrives at a count of the number of occupants in the vehicle, and optionally, even makes a determination as to whether each occupant was wearing a seatbelt and if he or she is moving after the accident. The phone or other communications system then automatically dials the EMS operator (such as 911 or through a telematics service such as OnStar®) and the information obtained from the interior monitoring systems is forwarded so that a determination can be made as to the number of ambulances and other equipment to send to the accident site, for example. Such vehicles will also have a system, such as the global positioning system, which permits the vehicle to determine its exact location and to forward this information to the EMS operator.

Thus, in basic embodiments of the invention, wave or other energy-receiving transducers are arranged in the vehicle at appropriate locations, trained if necessary depending on the particular embodiment, and function to determine whether a life form is present in the vehicle and if so, how many life forms are present and where they are located etc. To this end, transducers can be arranged to be operative at only a single seating locations or at multiple seating locations with a provision being made to eliminate repetitive count of occupants. A determination can also be made using the transducers as to whether the life forms are humans, or more specifically, adults, child in child seas, etc. As noted above and below, this is possible using pattern recognition techniques. Moreover, the processor or processors associated with the transducers can be trained to determine the location of the life forms, either periodically or continuously or possibly only immediately before, during and after a crash. The location of the life forms can be as general or as specific as necessary depending on the system requirements, i.e., a determination can be made that a human is situated on the driver's seat in a normal position (general) or a determination can be made that a human is situated on the driver's seat and is leaning forward and/or to the side at a specific angle as well as the position of his or her extremities and head and chest (specifically). The degree of detail is limited by several factors, including, for example, the number and position of transducers and training of the pattern recognition algorithm.

In addition to the use of transducers to determine the presence and location of occupants in a vehicle, other sensors could also be used. For example, a heartbeat sensor which determines the number and presence of heartbeats can also be arranged in the vehicle, which would thus also determine the number of occupants as the number of occupants would be equal to the number of heartbeats. Conventional heartbeat sensors can be adapted to differentiate between a heartbeat of an adult, a heartbeat of a child and a heartbeat of an animal. As its name implies, a heartbeat sensor detects a heartbeat, and the magnitude thereof, of a human occupant of the seat, if such a human occupant is present. The output of the heartbeat sensor is input to the processor of the interior monitoring system. One heartbeat sensor for use in the invention may be of the types as disclosed in McEwan (U.S. Pat. Nos. 5,573,012 and 5,766,208 which are incorporated herein in their entirety by reference). The heartbeat sensor can be positioned at any convenient position relative to the seats where occupancy is being monitored. A preferred location is within the vehicle seatback.

An alternative way to determine the number of occupants is to monitor the weight being applied to the seats, i.e., each seating location, by arranging weight sensors at each seating location which might also be able to provide a weight distribution of an object on the seat. Analysis of the weight and/or weight distribution by a predetermined method can provide an indication of occupancy by a human, an adult or child, or an inanimate object.

Another type of sensor which is not believed to have been used in an interior monitoring system heretofore is a micropower impulse radar (MIR) sensor which determines motion of an occupant and thus can determine his or her heartbeat (as evidenced by motion of the chest). Such an MIR sensor can be arranged to detect motion in a particular area in which the occupant's chest would most likely be situated or could be coupled to an arrangement which determines the location of the occupant's chest and then adjusts the operational field of the MIR sensor based on the determined location of the occupant's chest. A motion sensor utilizing a micro-power impulse radar (MIR) system

as disclosed, for example, in McEwan (U.S. Pat. No. 5,361,070, which is incorporated herein by reference), as well as many other patents by the same inventor. Motion sensing is accomplished by monitoring a particular range from the sensor as disclosed in that patent. MIR is one form of radar which has applicability to occupant sensing and can be mounted at various locations in the vehicle. It has an advantage over ultrasonic sensors in that data can be acquired at a higher speed and thus the motion of an occupant can be more easily tracked. The ability to obtain returns over the entire occupancy range is somewhat more difficult than with ultrasound resulting in a more expensive system overall. MIR has additional advantages in lack of sensitivity to temperature variation and has a comparable resolution to about 40 kHz ultrasound. Resolution comparable to higher frequency is also possible. Additionally, multiple MIR sensors can be used when high speed tracking of the motion of an occupant during a crash is required since they can be individually pulsed without interfering with each through time division multiplexing.

An alternative way to determine motion of the occupant (s) is to monitor the weight distribution of the occupant whereby changes in weight distribution after an accident would be highly suggestive of movement of the occupant. A system for determining the weight distribution of the occupants could be integrated or otherwise arranged in the seats **620**, **720** of the vehicle and several patents and publications describe such systems.

More generally, any sensor which determines the presence and health state of an occupant can also be integrated into the vehicle interior monitoring system in accordance with the invention. For example, a sensitive motion sensor can determine whether an occupant is breathing and a chemical sensor can determine the amount of carbon dioxide, or the concentration of carbon dioxide, in the air in the vehicle which can be correlated to the health state of the occupant(s). The motion sensor and chemical sensor can be designed to have a fixed operational field situated where the occupant's mouth is most likely to be located. In this manner, detection of carbon dioxide in the fixed operational field could be used as an indication of the presence of a human occupant in order to enable the determination of the number of occupants in the vehicle. In the alternative, the motion sensor and chemical sensor can be adjustable and adapted to adjust their operational field in conjunction with a determination by an occupant position and location sensor which would determine the location of specific parts of the occupant's body, e.g., his or her chest or mouth. Furthermore, an occupant position and location sensor can be used to determine the location of the occupant's eyes and determine whether the occupant is conscious, i.e., whether his or her eyes are open or closed or moving.

The use of chemical sensors can also be used to detect whether there is blood present in the vehicle, for example, after an accident. Additionally, microphones can detect whether there is noise in the vehicle caused by groaning, yelling, etc., and transmit any such noise through the cellular or other communication connection to a remote listening facility (such as operated by OnStar®).

FIG. **3** shows a schematic diagram of an embodiment of the invention including a system for determining the presence and health state of any occupants of the vehicle and a telecommunications link. This embodiment includes means for determining the presence of any occupants **410** which may take the form of a heartbeat sensor or motion sensor as described above and means for determining the health state of any occupants **412**. The latter means may be integrated into the means for determining the presence of any occupants, i.e., one and the same component, or separate therefrom. Further, means for determining the location, and optionally velocity, of the occupants or one or more parts thereof **414** are provided and may be any conventional occupant position sensor or preferably, one of the occupant position sensors as described herein (e.g., those utilizing waves. electromagnetic radiation or electric fields) or as described in the current assignee's patents and patent applications referenced above.

A processor **416** is coupled to the presence determining means **410**, the health state determining means **412** and the location determining means **414**. A communications unit **418** is coupled to the processor **416**. The processor **416** and/or communications unit **418** can also be coupled to microphones **420** that can be distributed throughout the vehicle and include voice-processing circuitry to enable the occupant(s) to effect vocal control of the processor **416**, communications unit **418** or any coupled component or oral communications via the communications unit **418**. The processor **416** is also coupled to another vehicular system, component or subsystem **422** and can issue control commands to effect adjustment of the operating conditions of the system, component or subsystem. Such a system, component or subsystem can be the heating or air-conditioning system, the entertainment system, an occupant restraint device such as an airbag, a glare prevention system, etc. Also, a positioning system **424** could be coupled to the processor **416** and provides an indication of the absolute position of the vehicle, preferably using satellite-based positioning technology (e.g., a GPS receiver).

In normal use (other than after a crash), the presence determining means **410** determine whether any human occupants are present, i.e., adults or children, and the location determining means **414** determine the occupant's location. The processor **416** receives signals representative of the presence of occupants and their location and determines whether the vehicular system, component or subsystem **422** can be modified to optimize its operation for the specific arrangement of occupants. For example, if the processor **416** determines that only the front seats in the vehicle are occupied, it could control the heating system to provide heat only through vents situated to provide heat for the front-seated occupants.

Another possible vehicular system, component or subsystem is a navigational aid, i.e., a route display or map. In this case, the position of the vehicle as determined by the positioning system **424** is conveyed through processor **416** to the communications unit **418** to a remote facility and a map is transmitted from this facility to the vehicle to be displayed on the route display. If directions are needed, a request for the same could be entered into an input unit **426** associated with the processor **416** and transmitted to the facility. Data for the display map and/or vocal instructions could be transmitted from this facility to the vehicle.

Moreover, using this embodiment, it is possible to remotely monitor the health state of the occupants in the vehicle and most importantly, the driver. The health state determining means **412** may be used to detect whether the driver's breathing is erratic or indicative of a state in which the driver is dozing off. The health state determining means **412** could also include a breath-analyzer to determine whether the driver's breath contains alcohol. In this case, the health state of the driver is relayed through the processor **416** and the communications unit **418** to the remote facility and appropriate action can be taken. For example, it would be possible to transmit a command to the vehicle to activate an

alarm or illuminate a warning light or if the vehicle is equipped with an automatic guidance system and ignition shut-off, to cause the vehicle to come to a stop on the shoulder of the roadway or elsewhere out of the traffic stream. The alarm, warning light, automatic guidance system and ignition shut-off are thus particular vehicular components or subsystems represented by **422**.

In use after a crash, the presence determining means **410**, health state determining means **412** and location determining means **414** can obtain readings from the passenger compartment and direct such readings to the processor **416**. The processor **416** analyzes the information and directs or controls the transmission of the information about the occupant(s) to a remote, manned facility. Such information would include the number and type of occupants, i.e., adults, children, infants, whether any of the occupants have stopped breathing or are breathing erratically, whether the occupants are conscious (as evidenced by, e.g., eye motion), whether blood is present (as detected by a chemical sensor) and whether the occupants are making noise. Moreover, the communications link through the communications unit **418** can be activated immediately after the crash to enable personnel at the remote facility to initiate communications with the vehicle.

An occupant sensing system can also involve sensing for the presence of a living occupant in a trunk of a vehicle or in a closed vehicle, for example, when a child is inadvertently left in the vehicle or enters the trunk and the trunk closes. To this end, a SAW-based chemical sensor **250** is illustrated in FIG. **4**A for mounting in a vehicle trunk as illustrated in FIG. **4**. The chemical sensor **250** is designed to measure carbon dioxide concentration through the mass loading effects as described in U.S. Pat. No. 4,895,017, which is incorporated by reference herein, with a polymer coating selected that is sensitive to carbon dioxide. The speed of the surface acoustic wave is a function of the carbon dioxide level in the atmosphere. Section **252** of the chemical sensor **250** contains a coating of such a polymer and the acoustic velocity in this section is a measure of the carbon dioxide concentration. Temperature effects are eliminated through a comparison of the sonic velocities in sections **251** and **252** as described above.

Thus, when trunk lid **260** is closed and a source of carbon dioxide such as a child or animal is trapped within the trunk, the chemical sensor **250** will provide information indicating the presence of the carbon dioxide producing object to the interrogator which can then release the trunk lock permitting trunk to automatically open. In this manner, the problem of children and animals suffocating in closed trunks is eliminated. Alternately, information that a person or animal is trapped in a trunk can be sent by the telematics system to law enforcement authorities or other location remote from the vehicle.

A similar device can be distributed at various locations within the passenger compartment of vehicle along with a combined temperature sensor. If the car has been left with a child or other animal while owner is shopping, for example, and if the temperature rises within the vehicle to an unsafe level or, alternately, if the temperature drops below an unsafe level, then the vehicle can be signaled to take appropriate action which may involve opening the windows or starting the vehicle with either air conditioning or heating as appropriate. Alternately, information that a person or animal is trapped within a vehicle can be sent by the telematics system to law enforcement authorities or other location remote from the vehicle. Thus, through these simple wireless powerless sensors, the problem of suffocation either from lack of oxygen or death from excessive heat or cold can all be solved in a simple, low-cost manner through using an interrogator as disclosed in the current assignee's U.S. patent application Ser. No. 10/079,065 incorporated by reference herein in its entirety.

Additionally, a sensitive layer on a SAW can be made to be sensitive to other chemicals such as water vapor for humidity control or alcohol for drunk driving control. Similarly, the sensitive layer can be designed to be sensitive to carbon monoxide thereby preventing carbon monoxide poisoning. Many other chemicals can be sensed for specific applications such as to check for chemical leaks in commercial vehicles, for example. Whenever such a sensor system determines that a dangerous situation is developing, an alarm can be sounded and/or the situation can be automatically communicated to an off vehicle location through telematics, a cell phone such as a 911 call, the Internet or though a subscriber service such as OnStar®.

Described above is a system for determining the status of occupants in a vehicle, and in the event of an accident or at any other appropriate time, transmitting the status of the occupants, and optionally additional information, via a communications channel or link to a remote monitoring facility. In addition to the status of the occupant, it is also important to be able to analyze the operating conditions of the vehicle and detect when a component of the vehicle is about to fail. By notifying the driver of the impending failure of the component, appropriate corrective action can be taken to avoid such failure.

The operating conditions of the vehicle can also be transmitted along with the status of the occupants to a remote monitoring facility. The operating conditions of the vehicle include whether the motor is running and whether the vehicle is moving. Thus, in a general embodiment in which information on both occupancy of the vehicle and the operating conditions of the vehicle are transmitted, one or more properties or characteristics of occupancy of the vehicle are determined, such constituting information about the occupancy of the vehicle, and one or more states of the vehicle or of a component of the vehicle is determined, such constituting information about the operation of the vehicle. The information about the occupancy of the vehicle and operation of the vehicle are selectively transmitted, possibly the information about occupancy to an emergency response center and the information about the vehicle to a dealer or repair facility.

Transmission of the information about the operation of the vehicle, i.e., diagnostic information, may be achieved via a satellite and/or via the Internet. The vehicle would thus include appropriate electronic hardware and/or software to enable the transmission of a signal to a satellite, from where it could be re-transmitted to a remote location, and/or to enable the transmission to a web site or host computer. In the latter case, the vehicle could be assigned a domain name or e-mail address for identification or transmission origination purposes.

It is important to appreciate that the preferred embodiment of the vehicle diagnostic unit described below performs the diagnosis, i.e., processes the input from the various sensors, on the vehicle using for example a processor embodying a pattern recognition technique such as a neural network. The processor thus receives data or signals from the sensors and generates an output indicative or representative of the operating conditions of the vehicle or its component. A signal could thus be generated indicative of an underinflated tire, or an overheating engine.

For the discussion below, the following terms are defined as follows:

The term "component" refers to any part or assembly of parts which is mounted to or a part of a motor vehicle and which is capable of emitting a signal representative of its operating state. The following is a partial list of general automobile and truck components, the list not being exclusive:

engine;

transmission;

brakes and associated brake assembly;

tires;

wheel;

steering wheel and steering column assembly;

water pump;

alternator;

shock absorber;

wheel mounting assembly;

radiator;

battery;

oil pump;

fuel pump;

air conditioner compressor;

differential gear;

exhaust system;

fan belts;

engine valves;

steering assembly;

vehicle suspension including shock absorbers;

vehicle wiring system; and

engine cooling fan assembly.

The term "sensor" refers to any measuring or sensing device mounted on a vehicle or any of its components including new sensors mounted in conjunction with the diagnostic module in accordance with the invention. A partial, non-exclusive list of common sensors mounted on an automobile or truck is as follows:

airbag crash sensor;

accelerometer;

microphone;

camera;

antenna, capacitance sensor-or other electromagnetic wave sensor;

stress or strain sensor;

pressure sensor;

weight sensor;

magnetic field sensor;

coolant thermometer;

oil pressure sensor;

oil level sensor;

air flow meter;

voltmeter;

ammeter;

humidity sensor;

engine knock sensor;

oil turbidity sensor;

throttle position sensor;

steering wheel torque sensor;

wheel speed sensor;

tachometer;

speedometer;

other velocity sensors;

other position or displacement sensors;

oxygen sensor;

yaw, pitch and roll angular sensors;

clock;

odometer;

power steering pressure sensor;

pollution sensor;

fuel gauge;

cabin thermometer;

transmission fluid level sensor;

gyroscopes or other angular rate sensors including yaw, pitch and roll rate sensors;

coolant level sensor;

transmission fluid turbidity sensor;

break pressure sensor;

tire pressure sensor;

tire temperature sensor, and

coolant pressure sensor.

The term "signal" herein refers to any time varying output from a component including electrical, acoustic, thermal, or electromagnetic radiation, or mechanical vibration.

Sensors on a vehicle are generally designed to measure particular parameters of particular vehicle components. However, frequently these sensors also measure outputs from other vehicle components. For example, electronic airbag crash sensors currently in use contain an accelerometer for determining the accelerations of the vehicle structure so that the associated electronic circuitry of the airbag crash sensor can determine whether a vehicle is experiencing a crash of sufficient magnitude so as to require deployment of the airbag. This accelerometer continuously monitors the vibrations in the vehicle structure regardless of the source of these vibrations. If a wheel is out of balance, or if there is extensive wear of the parts of the front wheel mounting assembly, or wear in the shock absorbers, the resulting abnormal vibrations or accelerations can, in many cases, be sensed by the crash sensor accelerometer. There are other cases, however, where the sensitivity or location of the airbag crash sensor accelerometer is not appropriate and one or more additional accelerometers may be mounted onto a vehicle for the purposes of this invention. Some airbag crash sensors are not sufficiently sensitive accelerometers or have sufficient dynamic range for the purposes herein.

Every component of a vehicle emits various signals during its life. These signals can take the form of electromagnetic radiation, acoustic radiation, thermal radiation, vibrations transmitted through the vehicle structure, and voltage or current fluctuations, depending on the particular component. When a component is functioning normally, it may not emit a perceptible signal. In that case, the normal signal is no signal, i.e., the absence of a signal. In most cases, a component will emit signals that change over its life and it is these changes which contain information as to the state of the component, e.g., whether failure of the component is impending. Usually components do not fail without warning. However, most such warnings are either not perceived or if perceived are not understood by the vehicle operator until the component actually fails and, in some cases, a breakdown of the vehicle occurs. In a few years, it is expected that various roadways will have systems for automatically guiding vehicles operating thereon. Such systems

have been called "smart highways" and are part of the field of intelligent transportation systems (ITS). If a vehicle operating on such a smart highway were to breakdown, serious disruption of the system could result and the safety of other users of the smart highway could be endangered.

In accordance with the invention, each of these signals emitted by the vehicle components is converted into electrical signals and then digitized (i.e., the analog signal is converted into a digital signal) to create numerical time series data which is then entered into a processor. Pattern recognition algorithms then are applied in the processor to attempt to identify and classify patterns in this time series data. For a particular component, such as a tire for example, the algorithm attempts to determine from the relevant digital data whether the tire is functioning properly or whether it requires balancing, additional air, or perhaps replacement.

Frequently, the data entered into the computer needs to be preprocessed before being analyzed by a pattern recognition algorithm. The data from a wheel speed sensor, for example, might be used as is for determining whether a particular tire is operating abnormally in the event it is unbalanced, whereas the integral of the wheel speed data over a long time period (a preprocessing step), when compared to such sensors on different wheels, might be more useful in determining whether a particular tire is going flat and therefore needs air. In some cases, the frequencies present in a set of data are a better predictor of component failures than the data itself For example, when a motor begins to fail due to worn bearings, certain characteristic frequencies began to appear. In most cases, the vibrations arising from rotating components, such as the engine, will be normalized based on the rotational frequency as disclosed in the NASA TSP referenced above. Moreover, the identification of which component is causing vibrations present in the vehicle structure can frequently be accomplished through a frequency analysis of the data. For these cases, a Fourier transformation of the data is made prior to entry of the data into a pattern recognition algorithm. Other mathematical transformations are also made for particular pattern recognition purposes in practicing the teachings of this invention. Some of these include shifting and combining data to determine phase changes for example, differentiating the data, filtering the data, and sampling the data. Also, there exist certain more sophisticated mathematical operations that attempt to extract or highlight specific features of the data. This invention contemplates the use of a variety of these preprocessing techniques and the choice of which ones is left to the skill of the practitioner designing a particular diagnostic module.

Another technique that is contemplated for some implementations of this invention is the use of multiple accelerometers and/or microphones that will allow the system to locate the source of any measured vibrations based on the time of flight and/or triangulation techniques. Once a distributed accelerometer installation has been implemented to permit this source location, the same sensors can be used for smarter crash sensing as it will permit the determination of the location of the impact on the vehicle. Once the impact location is known, a highly tailored algorithm can be used to accurately forecast the crash severity making use of a knowledge on the force vs. crush properties of the vehicle at the impact location.

When a vehicle component begins to change its operating behavior, it is not always apparent from the particular sensors, if any, which are monitoring that component. The output from any one of these sensors can be normal even though the component is failing. By analyzing the output of a variety of sensors, however, the pending failure can be diagnosed. For example, the rate of temperature rise in the vehicle coolant, if it were monitored, might appear normal unless it were known that the vehicle was idling and not traveling down a highway at a high speed. Even the level of coolant temperature which is in the normal range could be in fact abnormal in some situations signifying a failing coolant pump, for example, but not detectable from the coolant thermometer alone.

The pending failure of some components is difficult to diagnose and sometimes the design of the component requires modification so that the diagnosis can be more readily made. A fan belt, for example, frequently begins failing by a cracking of the inner surface. The belt can be designed to provide a sonic or electrical signal when this cracking begins in a variety of ways. Similarly, coolant hoses can be designed with an intentional weak spot where failure will occur first in a controlled manner that can also cause a whistle sound as a small amount of steam exits from the hose. This whistle sound can then be sensed by a general purpose microphone, for example.

In FIG. **5**, a generalized component **800** emitting several signals which are transmitted along a variety of paths, sensed by a variety of sensors and analyzed by the diagnostic device in accordance with the invention is illustrated schematically. Component **800** is mounted to a vehicle **880** and during operation it emits a variety of signals such as acoustic **801**, electromagnetic radiation **802**, thermal radiation **803**, current and voltage fluctuations in conductor **804** and mechanical vibrations **805**. Various sensors are mounted in the vehicle to detect the signals emitted by the component **800**. These include one or more vibration sensors (accelerometers) **830**, **850** and/or gyroscopes also mounted to the vehicle, one or more acoustic sensors **810**, **851**, electromagnetic radiation sensor **815**, heat radiation sensor **820**, and voltage or current sensor **840**.

In addition, various other sensors **852**, **853** measure other parameters of other components that in some manner provide information directly or indirectly on the operation of component **800**. All of the sensors illustrated on FIG. **5** can be connected to a data bus **860**. A diagnostic module **870**, in accordance with the invention, can also be attached to the vehicle data bus **860** and receives the signals generated by the various sensors. The sensors may however be wirelessly connected to the diagnostic module **870** and be integrated into a wireless power and communications system or a combination of wired and wireless connections.

As shown in FIG. **5**, the diagnostic module **870** has access to the output data of each of the sensors that have information relative to the component **800**. This data appears as a series of numerical values each corresponding to a measured value at a specific point in time. The cumulative data from a particular sensor is called a time series of individual data points. The diagnostic module **870** compares the patterns of data received from each sensor individually, or in combination with data from other sensors, with patterns for which the diagnostic module has been trained to determine whether the component is functioning normally or abnormally.

Important to this invention is the manner in which the diagnostic module **870** determines a normal pattern from an abnormal pattern and the manner in which it decides what data to use from the vast amount of data available. This is accomplished using pattern recognition technologies such as artificial neural networks and training. The theory of neural networks including many examples can be found in several books on the subject including: (1) *Techniques And Application Of Neural Networks*, edited by Taylor, M. and Lisboa,

P., Ellis Horwood, West Sussex, England, 1993; (2) *Naturally Intelligent Systems*, by Caudill, M. and Butler, C., MIT Press, Cambridge Mass., 1990; (3) J. M. Zaruda, *Introduction to Artificial Neural Systems*, West publishing Co., N.Y., 1992, (4) *Digital Neural Networks*, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, N.J., 1993, Eberhart, R., Simpson, P., (5) Dobbins, R., *Computational Intelligence PC Tools*, Academic Press, Inc., 1996, Orlando, Fla., (6) Cristianini, N. and Shawe-Taylor, J. *An Introduction to Support Vector Machines and other kernal-based learning methods*, Cambridge University Press, Cambridge England, 2000; (7) *Proceedings of the* 2000 6*th* *IEEE International Workshop on Cellular Neural Networks and their Applications* (*CNNA* 2000), IEEE, Piscataway N.J.; and (8) Sinha, N. K. and Gupta, M. M. *Soft Computing& Intelligent Systems*, Academic Press 2000 San Diego, C.A., all of which are incorporated herein by reference. The neural network pattern recognition technology is one of the most developed of pattern recognition technologies. The invention described herein frequently uses combinations of neural networks to improve the pattern recognition process.

The neural network pattern recognition technology is one of the most developed of pattern recognition technologies. The neural network will be used here to illustrate one example of a pattern recognition technology but it is emphasized that this invention is not limited to neural networks. Rather, the invention may apply any known pattern recognition technology including sensor fusion and various correlation technologies. A brief description of a particular example of a neural network pattern recognition technology is set forth below.

Neural networks are constructed of processing elements known as neurons that are interconnected using information channels call interconnects. Each neuron can have multiple inputs but only one output. Each output however is usually connected to all other neurons in the next layer. The neurons in the first layer operate collectively on the input data as described in more detail below. Neural networks learn by extracting relational information from the data and the desired output. Neural networks have been applied to a wide variety of pattern recognition problems including automobile occupant sensing, speech recognition, optical character recognition, and handwriting analysis.

To train a neural network, data is provided in the form of one or more time series that represents the condition to be diagnosed as well as normal operation. As an example, the simple case of an out of balance tire will be used. Various sensors on the vehicle can be used to extract information from signals emitted by the tire such as an accelerometer, a torque sensor on the steering wheel, the pressure output of the power steering system, a tire pressure monitor or tire temperature monitor. Other sensors that might not have an obvious relationship to tire unbalance are also included such as, for example, the vehicle speed or wheel speed that can be determined from the ABS system. Data is taken from a variety of vehicles where the tires were accurately balanced under a variety of operating conditions also for cases where varying amounts of unbalance was intentionally introduced. Once the data had been collected, some degree of preprocessing or feature extraction is usually performed to reduce the total amount of data fed to the neural network. In the case of the unbalanced tire, the time period between data points might be chosen such that there are at least ten data points per revolution of the wheel. For some other application, the time period might be one minute or one millisecond.

Once the data has been collected, it is processed by a neural network-generating program, for example, if a neural network pattern recognition system is to be used. Such programs are available commercially, e.g., from NeuralWare of Pittsburgh, Pa. or from International Scientific Research, Inc., of Romeo Mich. for modular neural networks. The program proceeds in a trial and error manner until it successfully associates the various patterns representative of abnormal behavior, an unbalanced tire, with that condition. The resulting neural network can be tested to determine if some of the input data from some of the sensors, for example, can be eliminated. In this way, the engineer can determine what sensor data is relevant to a particular diagnostic problem. The program then generates an algorithm that is programmed onto a microprocessor, microcontroller, neural processor, FPGA, or DSP (herein collectively referred to as a microprocessor or processor). Such a microprocessor appears inside the diagnostic module **870** in FIG. **5**. Once trained, the neural network, as represented by the algorithm, will now recognize an unbalanced tire on a vehicle when this event occurs. At that time, when the tire is unbalanced, the diagnostic module **870** will output a message to the driver indicating that the tire should be now be balanced as described in more detail below. The message to the driver is provided by output means coupled to or incorporated within the module **870** and may be, e.g., a light on the dashboard, a vocal tone or any other recognizable indication apparatus. A similar message may also be sent to the dealer or other repair facility or remote facility.

It is important to note that there may be many neural networks involved in a total vehicle diagnostic system. These can be organized either in parallel, series, as an ensemble, cellular neural network or as a modular neural network system. In one implementation of a modular neural network, a primary neural network identifies that there is an abnormality and tries to identify the likely source. Once a choice has been made as to the likely source of the abnormality, another of a group of neural networks is called upon to determine the exact cause of the abnormality. In this manner, the neural networks are arranged in a tree pattern with each neural network trained to perform a particular pattern recognition task.

Discussions on the operation of a neural network can be found in the above references on the subject and are well understood by those skilled in the art. Neural networks are the most well known of the pattern recognition technologies based on training, although neural networks have only recently received widespread attention and have been applied to only very limited and specialized problems in motor vehicles. Other non-training based pattern recognition technologies exist, such as fuzzy logic. However, the programming required to use fuzzy logic, where the patterns must be determine by the programmer, render these systems impractical for general vehicle diagnostic problems such as described herein. Therefore, preferably the pattern recognition systems that learn by training are used herein.

The neural network is the first highly successful of what will be a variety of pattern recognition techniques based on training. There is nothing that suggests that it is the only or even the best technology. The characteristics of all of these technologies which render them applicable to this general diagnostic problem include the use of time-based input data and that they are trainable. In all cases, the pattern recognition technology learns from examples of data characteristic of normal and abnormal component operation.

A diagram of one example of a neural network used for diagnosing an unbalanced tire, for example, based on the teachings of this invention is shown in FIG. **6**. The process can be programmed to periodically test for an unbalanced

tire. Since this need be done only infrequently, the same processor can be used for many such diagnostic problems. When the particular diagnostic test is run, data from the previously determined relevant sensors is preprocessed and analyzed with the neural network algorithm. For the unbalanced tire, using the data from an accelerometer for example, the digital acceleration values from the analog to digital converter in the accelerometer are entered into nodes I through n and the neural network algorithm compares the pattern of values on nodes 1 through n with patterns for which it has been trained as follows.

Each of the input nodes is connected to each of the second layer nodes, h-**1**, h-**2**, . . . , h-n, called the hidden layer, either electrically as in the case of a neural computer, or through mathematical functions containing multiplying coefficients called weights, in the manner described in more detail in the above references. At each hidden layer node, a summation occurs of the values from each of the input layer nodes, which have been operated on by functions containing the weights, to create a node value. Similarly, the hidden layer nodes are in like manner connected to the output layer node(s), which in this example is only a single node 0 representing the decision to notify the driver, and/or a remote facility, of the unbalanced tire. During the training phase, an output node value of 1, for example, is assigned to indicate that the driver should be notified and a value of 0 is assigned to not doing so. Once again, the details of this process are described in above-referenced texts and will not be presented in detail here.

In the example above, twenty input nodes were used, five hidden layer nodes and one output layer node. In this example, only one sensor was considered and accelerations from only one direction were used. If other data from other sensors such as accelerations from the vertical or lateral directions were also used, then the number of input layer nodes would increase. Again, the theory for determining the complexity of a neural network for a particular application has been the subject of many technical papers and will not be presented in detail here. Determining the requisite complexity for the example presented here can be accomplished by those skilled in the art of neural network design.

Briefly, the neural network described above defines a method, using a pattern recognition system, of sensing an unbalanced tire and determining whether to notify the driver, and/or a remote facility, and comprises the steps of:

(a) obtaining an acceleration signal from an accelerometer mounted on a vehicle;

(b) converting the acceleration signal into a digital time series;

(c) entering the digital time series data into the input nodes of the neural network;

(d) performing a mathematical operation on the data from each of the input nodes and inputting the operated on data into a second series of nodes wherein the operation performed on each of the input node data prior to inputting the operated on value to a second series node is different from that operation performed on some other input node data;

(e) combining the operated on data from all of the input nodes into each second series node to form a value at each second series node;

(f) performing a mathematical operation on each of the values on the second series of nodes and inputting this operated on data into an output series of nodes wherein the operation performed on each of the second series node data prior to inputting the operated on value to an output series node is different from that operation performed on some other second series node data;

(g) combining the operated on data from all of the second series nodes into each output series node to form a value at each output series node; and,

(h) notifying a driver if the value on one output series node is within a chosen range signifying that a tire requires balancing.

This method can be generalized to a method of predicting that a component of a vehicle will fail comprising the steps of:

(a) sensing a signal emitted from the component;

(b) converting the sensed signal into a digital time series;

(c) entering the digital time series data into a pattern recognition algorithm;

(d) executing the pattern recognition algorithm to determine if there exists within the digital time series data a pattern characteristic of abnormal operation of the component; and

(e) notifying a driver and/or a remote facility if the abnormal pattern is recognized.

The particular neural network described and illustrated above contains a single series of hidden layer nodes. In some network designs, more than one hidden layer is used, although only rarely will more than two such layers appear. There are of course many other variations of the neural network architecture illustrated above which appear in the referenced literature. For the purposes herein, therefore, "neural network" will be defined as a system wherein the data to be processed is separated into discrete values which are then operated on and combined in at least a two stage process and where the operation performed on the data at each stage is in general different for each discrete value and where the operation performed is at least determined through a training process.

The implementation of neural networks can take on at least two forms, an algorithm programmed on a digital microprocessor, FPGA, DSP or in a neural computer (including a cellular neural network or support vector machine). In this regard, it is noted that neural computer chips are now becoming available.

In the example above, only a single component failure was discussed using only a single sensor since the data from the single sensor contains a pattern which the neural network was trained to recognize as either normal operation of the component or abnormal operation of the component. The diagnostic module **870** contains preprocessing and neural network algorithms for a number of component failures. The neural network algorithms are generally relatively simple, requiring only a relatively small number of lines of computer code. A single general neural network program can be used for multiple pattern recognition cases by specifying different coefficients for the various terms, one set for each application. Thus, adding different diagnostic checks has only a small affect on the cost of the system. Also, the system has available to it all of the information available on the data bus. During the training process, the pattern recognition program sorts out from the available vehicle data on the data bus or from other sources, those patterns that predict failure of a particular component.

In FIG. **7**, a schematic of a vehicle with several components and several sensors is shown in their approximate locations on a vehicle along with a total vehicle diagnostic system in accordance with the invention utilizing a diagnostic module in accordance with the invention. A flow diagram of information passing from the various sensors

shown in FIG. 7 onto the vehicle data bus and thereby into the diagnostic device in accordance with the invention is shown in FIG. 8 along with outputs to a display for notifying the driver and to the vehicle cellular phone, or other communication device, for notifying the dealer, vehicle manufacturer or other entity concerned with the failure of a component in the vehicle. If the vehicle is operating on a smart highway, for example, the pending component failure information may also be communicated to a highway control system and/or to other vehicles in the vicinity so that an orderly exiting of the vehicle from the smart highway can be facilitated. FIG. 8 also contains the names of the sensors shown numbered on FIG. 7.

Sensor **901** is a crash sensor having an accelerometer (alternately one or more dedicated accelerometers **931** can be used), sensor **902** is represents one or more microphones, sensor **903** is a coolant thermometer, sensor **904** is an oil pressure sensor, sensor **905** is an oil level sensor, sensor **906** is an air flow meter, sensor **907** is a voltmeter, sensor **908** is an ammeter, sensor **909** is a humidity sensor, sensor **910** is an engine knock sensor, sensor 911 is an oil turbidity sensor, sensor **912** is a throttle position sensor, sensor **913** is a steering torque sensor, sensor **914** is a wheel speed sensor, sensor **915** is a tachometer, sensor **916** is a speedometer, sensor **917** is an oxygen sensor, sensor **918** is a pitch/roll sensor, sensor **919** is a clock, sensor **920** is an odometer, sensor **921** is a power steering pressure sensor sensor **922** is a pollution sensor, sensor **923** is a fuel gauge, sensor **924** is a cabin thermometer, sensor **925** is a transmission fluid level sensor, sensor **926** is a yaw sensor, sensor **927** is a coolant level sensor, sensor **928** is a transmission fluid turbidity sensor, sensor **929** is brake pressure sensor and sensor **930** is a coolant pressure sensor. Other possible sensors include a temperature transducer, a pressure transducer, a liquid level sensor, a flow meter, a position sensor, a velocity sensor, a RPM sensor, a chemical sensor and an angle sensor, angular rate sensor or gyroscope.

If a distributed group of acceleration sensors or accelerometers are used to permit a determination of the location of a vibration source, the same group can, in some cases, also be used to measure the pitch, yaw and/or roll of the vehicle eliminating the need for dedicated angular rate sensors. In addition, as mentioned above, such a suite of sensors can also be used to determine the location and severity of a vehicle crash and additionally to determine that the vehicle is on the verge of rolling over. Thus, the same suite of accelerometers optimally performs a variety of functions including inertial navigation, crash sensing, vehicle diagnostics, roll over sensing etc.

Consider now some examples. The following is a partial list of potential component failures and the sensors from the list on FIG. 8 that might provide information to predict the failure of the component:

Out of balance tires	901,913,914,915,920,921
Front end out of alignment	901,913,921,926
Tune up required	901,903,910,912,915,917,920,922
Oil change needed	903,904,905,911
Motor failure	901,902,903,904,905,906,910,912,915,917,922
Low tire pressure	901,913,914,915,920,921
Front end looseness	901,913,916,921,926
Cooling system failure	903,915,924,927,930
Alternator problems	901,902,907,908,915,919,920
Transmission problems	901,903,912,915,916,920,925,928
Differential problems	901,912,914

-continued

Brakes	901,902,914,918,920,926,929
Catalytic converter and muffler	901,902,912,915,922
Ignition	901,902,907,908,909,910,912,917,923
Tire wear	901,913,914,915,918,920,921,926
Fuel leakage	920,923
Fan belt slippage	901,902,903,907,908,912,915,919,920
Alternator deterioration	901,902,907,908,915,919
Coolant pump failure	901,902,903,924,927,930
Coolant hose failure	901,902,903,927,930
Starter failure	901,902,907,908,909,912,915
Dirty air filter	902,903,906,911,912,917,922

Several interesting facts can be deduced from a review of the above list. First, all of the failure modes listed can be at least partially sensed by multiple sensors. In many cases, some of the sensors merely add information to aid in the interpretation of signals received from other sensors. In today's automobile, there are few if any cases where multiple sensors are used to diagnose or predict a problem. In fact, there is virtually no failure prediction undertaken at all. Second, many of the failure modes listed require information from more than one sensor. Third, information for many of the failure modes listed cannot be obtained by observing one data point in time as is now done by most vehicle sensors. Usually an analysis of the variation in a parameter as a function of time is necessary. In fact, the association of data with time to create a temporal pattern for use in diagnosing component failures in automobile is unique to this invention as in the combination of several such temporal patterns. Fourth, the vibration measuring capability of the airbag crash sensor, or other accelerometer, is useful for most of the cases discussed above yet there is no such current use of accelerometers. The airbag crash sensor is used only to detect crashes of the vehicle. Fifth, the second most used sensor in the above list, a microphone, does not currently appear on any automobiles yet sound is the signal most often used by vehicle operators and mechanics to diagnose vehicle problems. Another sensor that is listed above which also does not currently appear on automobiles is a pollution sensor. This is typically a chemical sensor mounted in the exhaust system for detecting emissions from the vehicle. It is expected that this and other chemical sensors will be used more in the future.

In addition, from the foregoing depiction of different sensors which receive signals from a plurality of components, it is possible for a single sensor to receive and output signals from a plurality of components which are then analyzed by the processor to determine if any one of the components for which the received signals were obtained by that sensor is operating in an abnormal state. Likewise, it is also possible to provide for a multiplicity of sensors each receiving a different signal related to a specific component which are then analyzed by the processor to determine if that component is operating in an abnormal state. Note that neural networks can simultaneously analyze data from multiple sensors of the same type or different types.

The discussion above has centered on notifying the vehicle operator of a pending problem with a vehicle component. Today, there is great competition in the automobile marketplace and the manufacturers and dealers who are most responsive to customers are likely to benefit by increased sales both from repeat purchasers and new customers. The diagnostic module disclosed herein benefits the dealer by making him instantly aware, through the cellular telephone system, or other communication link, coupled to the diagnostic module or system in accordance with the

invention, when a component is likely to fail. As envisioned, on some automobiles, when the diagnostic module **870** detects a potential failure it not only notifies the driver through a display **980**, but also automatically notifies the dealer through a vehicle cellular phone **990** or other telematics communication link. The dealer can thus contact the vehicle owner and schedule an appointment to undertake the necessary repair at each party's mutual convenience. Contact by the dealer to the vehicle owner can occur as the owner is driving the vehicle, using a communications device. Thus, the dealer can contact the driver and informed him of their mutual knowledge of the problem and discuss scheduling maintenance to attend to the problem. The customer is pleased since a potential vehicle breakdown has been avoided and the dealer is pleased since he is likely to perform the repair work. The vehicle manufacturer also benefits by early and accurate statistics on the failure rate of vehicle components. This early warning system can reduce the cost of a potential recall for components having design defects. It could even have saved lives if such a system had been in place during the Firestone tire failure problem mentioned above. The vehicle manufacturer will thus be guided toward producing higher quality vehicles thus improving his competitiveness. Finally, experience with this system will actually lead to a reduction in the number of sensors on the vehicle since only those sensors that are successful in predicting failures will be necessary.

For most cases, it is sufficient to notify a driver that a component is about to fail through a warning display.

In some critical cases, action beyond warning the driver may be required. If, for example, the diagnostic module detected that the alternator was beginning to fail, in addition to warning the driver of this eventuality, the module could send a signal to another vehicle system to turn off all non-essential devices which use electricity thereby conserving electrical energy and maximizing the time and-distance that the vehicle can travel before exhausting the energy in the battery. Additionally, this system can be coupled to a system such as OnStar® or a vehicle route guidance system, and the driver can be guided to the nearest open repair facility or a facility of his or her choice.

In the discussion above, the diagnostic module of this invention assumes that a vehicle data bus exists which is used by all of the relevant sensors on the vehicle. Most vehicles today do not have a data bus although it is widely believed that most vehicles will have one in the near future. Naturally, the relevant signals can be transmitted to the diagnostic module through a variety of coupling means other than through a data bus and this invention is not limited to vehicles having a data bus. For example, the data can be sent wirelessly to the diagnostic module using the Bluetooth™ specification. In some cases, even the sensors do not have to be wired and can obtain their power via RF from the interrogator as is well known in the RFID -radio frequency identification (either silicon or surface acoustic wave (SAW) based)) field. Alternately an inductive or capacitive power transfer system can be used.

As can be appreciated from the above discussion, the invention described herein brings several new improvements to automobiles including, but not limited to, the use of pattern recognition technologies to diagnose potential vehicle component failures, the use of trainable systems thereby eliminating the need of complex and extensive programming, the simultaneous use of multiple sensors to monitor a particular component, the use of a single sensor to monitor the operation of many vehicle components, the monitoring of vehicle components which have no dedicated sensors, and the notification of both the driver and possibly an outside entity of a potential component failure in time so that the failure can be averted and vehicle breakdowns substantially eliminated. Additionally, improvements to the vehicle stability, crash avoidance, crash anticipation and occupant protection are available.

To implement a component diagnostic system for diagnosing the component utilizing a plurality of sensors not directly associated with the component, i.e., independent of the component, a series of tests are conducted. For each test, the signals received from the sensors are input into a pattern recognition training algorithm with an indication of whether the component is operating normally or abnormally (the component being intentionally altered to provide for abnormal operation). The data from the test are used to generate the pattern recognition algorithm, e.g., neural network, so that in use, the data from the sensors is input into the algorithm and the algorithm provides an indication of abnormal or normal operation of the component. Also, to provide a more versatile diagnostic module for use in conjunction with diagnosing abnormal operation of multiple components, tests may be conducted in which each component is operated abnormally while the other components are operating normally, as well as tests in which two or more components are operating abnormally. In this manner, the diagnostic module may be able to determine based on one set of signals from the sensors during use that either a single component or multiple components are operating abnormally.

Furthermore, the pattern recognition algorithm may be trained based on patterns within the signals from the sensors. Thus, by means of a single sensor, it would be possible to determine whether one or more components are operating abnormally. To obtain such a pattern recognition algorithm, tests are conducted using a single sensor, such as a microphone, and causing abnormal operation of one or more components, each component operating abnormally while the other components operate normally and multiple components operating abnormally. In this manner, in use, the pattern recognition algorithm may analyze a signal from a single sensor and determine abnormal operation of one or more components. Note that in some cases, simulations can be used to analytically generate the relevant data.

The invention is also particularly useful in light of the foreseeable implementation of smart highways. Smart highways will result in vehicles traveling down highways under partial or complete control of an automatic system, i.e., not being controlled by the driver. The on-board diagnostic system will thus be able to determine failure of a component prior to or upon failure thereof and inform the vehicle's guidance system to cause the vehicle to move out of the stream of traffic, i.e., onto a shoulder of the highway, in a safe and orderly manner. Moreover, the diagnostic system may be controlled or programmed to prevent the movement of the disabled vehicle back into the stream of traffic until the repair of the component is satisfactorily completed.

In a method in accordance with this embodiment, the operation of the component would be monitored and if abnormal operation of the component is detected, e.g., by any of the methods and apparatus disclosed herein (although other component failure systems may of course be used in this implementation), the guidance system of the vehicle which controls the movement of the vehicle would be notified, e.g., via a signal from the diagnostic module to the guidance system, and the guidance system would be programmed to move the vehicle out of the stream of traffic, or off of the restricted roadway, possibly to a service station or

dealer, upon reception of the particular signal from the diagnostic module. The automatic guidance systems for vehicles traveling on highways may be any existing system or system being developed, such as one based on satellite positioning techniques or ground-based positioning techniques. Since the guidance system may be programmed to ascertain the vehicle's position on the highway, it can determine the vehicle's current position, the nearest location out of the stream of traffic, or off of the restricted roadway, such as an appropriate shoulder or exit to which the vehicle may be moved, and the path of movement of the vehicle from the current position to the location out of the stream of traffic, or off of the restricted roadway. The vehicle may thus be moved along this path under the control of the automatic guidance system. In the alternative, the path may be displayed to a driver and the driver can follow the path, i.e., manually control the vehicle. The diagnostic module and/or guidance system may be designed to prevent re-entry of the vehicle into the stream of traffic, or off of the restricted roadway, until the abnormal operation of the component is satisfactorily addressed.

FIG. **9** is a flow chart of some of the methods for directing a vehicle off of a roadway if a component is operating abnormally. The component's operation is monitored at **440** and a determination is made at **442** whether its operation is abnormal. If not, the operation of the component is monitored further. If the operation of the component is abnormal, the vehicle can be directed off the roadway at **444**. More particularly, this can be accomplished by generating a signal indicating the abnormal operation of the component at **446**, directing this signal to a guidance system in the vehicle at **448** that guides movement of the vehicle off of the roadway at **450**. Also, if the component is operating abnormally, the current position of the vehicle and the location of a site off of the roadway can be determined at **452**, e.g., using satellite-based or ground-based location determining techniques, a path from the current location to the off-roadway location determined at **454** and then the vehicle directed along this path at **456**. Periodically, a determination is made at **458** whether the component's abnormality has been satisfactorily addressed and/or corrected and if so, the vehicle can re-enter the roadway and operation of the component begins again. If not, the re-entry of the vehicle onto the roadway is prevented at **460**.

FIG. **10** schematically shows the basic components for performing this method, i.e., a component operation monitoring system **462** (such as described above), an optional satellite-based or ground-based positioning system **464** and a vehicle guidance system **466**.

FIG. **11** illustrates the placement of a variety of sensors, primarily accelerometers and/or gyroscopes, which can be used to diagnose the state of the vehicle itself. Sensor **202** can be located in the headliner or attached to the vehicle roof above the side door. Typically, there can be two such sensors one on either side of the vehicle. Sensor **203** is shown in a typical mounting location midway between the sides of the vehicle attached to or near the vehicle roof above the rear window. Sensor **206** is shown in a typical mounting location in the vehicle trunk adjacent the rear of the vehicle. Either one, two or three such sensors can be used depending on the application. If three such sensors are use one would be adjacent each side of vehicle and one in the center. Sensor **204** is shown in a typical mounting location in the vehicle door and sensor **205** is shown in a typical mounting location on the sill or floor below the door. Sensor **207**, which can be also multiple sensors, is shown in a typical mounting location forward in the crush zone of the vehicle. Finally, sensor **208** can measure the acceleration of the firewall or instrument panel and is located thereon generally midway between the two sides of the vehicle. If three such sensors are used, one would be adjacent each vehicle side and one in the center.

In general, sensors **202–208** provide a measurement of the state of the vehicle, such as its velocity, acceleration, angular orientation or temperature, or a state of the location at which the sensor is mounted. Thus, measurements related to the state of the sensor would include measurements of the acceleration of the sensor, measurements of the temperature of the mounting location as well as changes in the state of the sensor and rates of changes of the state of the sensor. As such, any described use or function of the sensors **202–208** above is merely exemplary and is not intended to limit the form of the sensor or its function.

Each of the sensors **202–208** may be single axis, double axis or triaxial accelerometers and/or gyroscopes typically of the MEMS type. These sensors **202–208** can either be wired to the central control module or processor directly wherein they would receive power and transmit information, or they could be connected onto the vehicle bus or, in some cases, using RFID, SAW or similar technology, the sensors can be wireless and would receive their power through RF from one or more interrogators located in the vehicle. In this case, the interrogators can be connected either to the vehicle bus or directly to control module. Alternately, an inductive or capacitive power and information transfer system can be used.

One particular implementation will now be described. In this case, each of the sensors **202–208** is a single or dual axis accelerometer. They are made using silicon micromachined technology such as disclosed in U.S. Pat. Nos. 5,121,180 and 5,894,090. These are only representative patents of these devices and there exist more than 100 other relevant U.S. patents describing this technology. Commercially available MEMS gyroscopes such as from Systron Doner have accuracies of approximately one degree per second. In contrast, optical gyroscopes typically have accuracies of approximately one degree per hour. Unfortunately, the optical gyroscopes are prohibitively expensive for automotive applications. On the other hand, typical MEMS gyroscopes are not sufficiently accurate for many control applications.

The angular rate function can be obtained through placing accelerometers at two separated, non-co-located points in a vehicle and using the differential acceleration to obtain an indication of angular motion and angular acceleration. From the variety of accelerometers shown on FIG. **11**, it can be appreciated that not only will all accelerations of key parts of the vehicle be determined, but the pitch, yaw and roll angular rates can also be determined based on the accuracy of the accelerometers. By this method, low cost systems can be developed which, although not as accurate as the optical gyroscopes, are considerably more accurate than conventional MEMS gyroscopes. Alternately, it has been found that from a single package containing up to three low cost MEMS gyroscopes and three low cost MEMS accelerometers, when carefully calibrated, an accurate inertial measurement unit (IMU) can be constructed that performs as well as units costing a great deal more. Such a package is sold by Crossbow Technology, Inc. 41 Daggett Dr., San Jose, Calif. 95134. If this IMU is combined with a GPS system and sometimes other vehicle sensor inputs using a Kalman filter, accuracy approaching that of expensive military units can be achieved.

Instead of using two accelerometers at separate locations on the vehicle, a single conformal MEMS-IDT gyroscope

may be used. Such a conformal MEMS-IDT gyroscope is described in a paper by V. K. Karadan, Conformal MEMS-IDT Gyroscopes and Their Comparison With Fiber Optic Gyro, incorporated in its entirety herein. The MEMS-IDT gyroscope is based on the principle of surface acoustic wave (SAW) standing waves on a piezoelectric substrate. A surface acoustic wave resonator is used to create standing waves inside a cavity and the particles at the anti-nodes of the standing waves experience large amplitude of vibrations, which serves as the reference vibrating motion for the gyroscope. Arrays of metallic dots are positioned at the anti-node locations so that the effect of Coriolis force due to rotation will acoustically amplify the magnitude of the waves. Unlike other MEMS gyroscopes, the MEMS-IDT gyroscope has a planar configuration with no suspended resonating mechanical structures. Other SAW-based gyroscopes are also now under development.

The system of FIG. **11** using dual axis accelerometers, or the IMU Kalman filter system, therefore provides a complete diagnostic system of the vehicle itself and its dynamic motion. Such a system is far more accurate than any system currently available in the automotive market. This system provides very accurate crash discrimination since the exact location of the crash can be determined and, coupled with a knowledge of the force deflection characteristics of the vehicle at the accident impact site, an accurate determination of the crash severity and thus the need for occupant restraint deployment can be made. Similarly, the tendency of a vehicle to roll over can be predicted in advance and signals sent to the vehicle steering, braking and throttle systems to attempt to ameliorate the rollover situation or prevent it. In the event that it cannot be prevented, the deployment side curtain airbags can be initiated in a timely manner.

Similarly, the tendency of the vehicle to the slide or skid can be considerably more accurately determined and again the steering, braking and throttle systems commanded to minimize the unstable vehicle behavior.

Thus, through the sample deployment of inexpensive accelerometers at a variety of locations in the vehicle, or the IMU Kalman filter system significant improvements are made in the vehicle stability control, crash sensing, rollover sensing, and resulting occupant protection technologies.

Finally, as mentioned above, the combination of the outputs from these accelerometer sensors and the output of strain gage weight sensors in a vehicle seat, or in or on a support structure of the seat, can be used to make an accurate assessment of the occupancy of the seat and differentiate between animate and inanimate occupants as well as determining where in the seat the occupants are sitting. This can be done by observing the acceleration signals from the sensors of FIG. **11** and simultaneously the dynamic strain gage measurements from seat mounted strain gages. The accelerometers provide the input function to the seat and the strain gages measure the reaction of the occupying item to the vehicle acceleration and thereby provide a method of determining dynamically the mass of the occupying item and its location. This is particularly important during occupant position sensing during a crash event. By combining the outputs of the accelerometers and the strain gages and appropriately processing the same, the mass and weight of an object occupying the seat can be determined as well as the gross motion of such an object so that an assessment can be made as to whether the object is a life form such as a human being.

For this embodiment, sensor **209** represents one or more strain gage weight sensors mounted on the seat or in connection with the seat or its support structure. Suitable mounting locations and forms of weight sensors are discussed in the current assignee's U.S. patent application Ser. No. 09/193,209 and contemplated for use in this invention as well. The mass or weight of the occupying item of the seat can thus be measured based on the dynamic measurement of the strain gages with optional consideration of the measurements of accelerometers on the vehicle, which are represented by any of sensors **202–208**.

FIG. **12** shows a schematic of the integration of the occupant sensing with a telematics link and the vehicle diagnosis with a telematics link. As envisioned, the occupant sensing system **1000** includes those components which determine the presence, position, health state, and other information relating to the occupants, for example the transducers discussed above with reference to FIGS. **1–3** and the SAW device discussed above with reference to FIG. **4**. Information relating to the occupants includes information as to what the driver is doing, talking on the phone, communicating with OnStar® or other route guidance, listening to the radio, sleeping, drunk, drugged, having a heart attack The occupant sensing system may also be any of those systems and apparatus described in any of the current assignee's above-referenced patents and patent applications incorporated by reference herein, or any other comparable occupant sensing system which performs any or all of the same functions as they relate to occupant sensing. Examples of sensors which might be installed on a vehicle and constitute the occupant sensing system include heartbeat sensors, motion sensors, weight sensors, microphones and optical sensors.

A crash sensor **1002** is provided and determines when the vehicle experiences a crash. Crash sensor **1002** may be any type of crash sensor.

Vehicle sensors **1004** include sensors which detect the operating conditions of the vehicle such as those sensors discussed with reference to FIGS. **4–8** above. Also included are tire sensors such as disclosed in U.S. patent application Ser. No. 10/079,065. Other examples include velocity and acceleration sensors, and angular and angular rate pitch, roll and yaw sensors. Of particular importance are sensors that tell what the car is doing: speed, skidding, sliding, location, communicating with other cars or the infrastructure, etc.

Environment sensors **1006** includes sensors which provide data to the operating environment of the vehicle, e.g., the inside and outside temperatures, the time of day, the location of the sun and lights, the locations of other vehicles, rain, snow, sleet, visibility (fog), general road condition information, pot holes, ice, snow cover, road visibility, assessment of traffic, video pictures of an accident, etc. Possible sensors include optical sensors which obtain images of the environment surrounding the vehicle, blind spot detectors which provides data on the blind spot of the driver, automatic cruise control sensors that can provide images of vehicles in front of the host vehicle, various radar devices which provide the position of other vehicles and objects relative to the subject vehicle.

The occupant sensing system **1000**, crash sensors **1002**, vehicle sensors **1004**, environment sensors **1006** all are coupled to a communications device **1008** which may contain a memory unit and appropriate electrical hardware to communicate with all of the sensors, process data from the sensors, and transmit data from the sensors. The memory unit would be useful to store data from the sensors, updated periodically, so that such information could be transmitted at set time intervals.

The communications device **308** can be designed to transmit information to any number of different types of

facilities. For example, the communications device **1008** would be designed to transmit information to an emergency response facility **1010** in the event of an accident involving the vehicle. The transmission of the information would be triggered by a signal from the crash sensor **1002** that the vehicle was experiencing a crash or experienced a crash. The information transmitted would come from the occupant sensing system **1000** so that the emergency response could be tailored to the status of the occupants. For example, if the vehicle was determined to have ten occupants, multiple ambulances might be sent than if the vehicle contained only a single occupant. Also, if the occupants are determined not be breathing, then a higher priority call with living survivors might receive assistance first. As such, the information from the occupant sensing system **1000** would be used to prioritize the duties of the emergency response personnel.

Information from the vehicle sensors **1004** and environment sensors **1006** could also be transmitted to law enforcement authorities **1014** in the event of an accident so that the cause(s) of the accident could be determined. Such information can also include information from the occupant sensing system **1000**, which might reveal that the driver was talking on the phone, putting on make-up, or another distracting activity, information from the vehicle sensors **1004** which might reveal a problem with the vehicle, and information from the environment sensors **1006** which might reveal the existence of slippery roads, dense fog and the like.

Information from the occupant sensing system **1000**, vehicle sensors **1004** and environment sensors **1006** could also be transmitted to the vehicle manufacturer **1016** in the event of an accident so that a determination can be made as to whether failure of a component of the vehicle causes or contributed to the cause of the accident. For example, the vehicle sensors might determine that the tire pressure was too low so that advice can be disseminated to avoid maintaining the tire pressure too low in order to avoid an accident. Information from the vehicle sensors **1004** relating to component failure could be transmitted to a dealer/repair facility **1012** which could schedule maintenance to correct the problem.

The communications device **1008** could be designed to transmit particular information to each site, i.e., only information important to be considered by the personnel at that site. For example, the emergency response personnel have no need for the fact that the tire pressure was too low but such information is important to the law enforcement authorities **1014** (for the possible purpose of issuing a recall of the tire and/or vehicle) and the vehicle manufacturer **1016**.

The communication device can be a cellular phone, OnStar® or other subscriber-based telematics system, a peer-to-peer vehicle communication system that eventually communicates to the infrastructure and then, perhaps, to the Internet with email to the dealer, manufacturer, vehicle owner, law enforcement authorities or others. It can also be a vehicle to LEO or Geostationary satellite system such as SkyBytes which can then forward the information to the appropriate facility either directly or through the Internet.

The communication may need to be secret so as not to violate the privacy of the occupants and thus encrypted communication may in many cases be required. Other innovations described herein include the transmission of any video data from a vehicle to another vehicle or to a facility remote from the vehicle by any means such as a telematics communication system such as OnStar®, a cellular phone system, a communication via GEO, geocentric or other satellite system and any communication that communicates the results of a pattern recognition system analysis. Also, any communication from a vehicle that combines sensor information with location information.

When optical sensors are provided as part of the occupant sensing system **1000**, video conferencing becomes a possibility, whether or not the vehicle experiences a crash. That is, the occupants of the vehicle can engage in a video conference with people at another location **1018** via establishment of a communications channel by the communications device **1008**.

The vehicle diagnostic system described above using a telematics link can transmit information from any type of sensors on the vehicle.

In one particular use of the invention, a wireless sensing and communication system is provided whereby the information or data obtained through processing of input from sensors of the wireless sensing and communication system is further transmitted for reception by a remote facility. Thus, in such a construction, there is an intra-vehicle communications between the sensors on the vehicle and a processing system (control module, computer or the like) and remote communications between the same or a coupled processing system (control module, computer or the like). The electronic components for the intra-vehicle communication may be designed to transmit and receive signals over short distances whereas the electronic components which enable remote communications should be designed to transmit and receive signals over relatively long distances.

The wireless sensing and communication system includes sensors that are located on the vehicle or in the vicinity of the vehicle and which provide information which is transmitted to one or more interrogators in the vehicle by wireless radio frequency means, using wireless radio frequency transmission technology. In some cases, the power to operate a particular sensor is supplied by the interrogator while in other cases, the sensor is independently connected to either a battery, generator, vehicle power source or some source of power external to the vehicle.

The sensors for a system installed in a vehicle would likely include tire pressure, temperature and acceleration monitoring sensors, weight or load measuring sensors, switches, temperature, acceleration, angular position, angular rate, angular acceleration, proximity, rollover, occupant presence, humidity, presence of fluids or gases, strain, road condition and friction, chemical sensors and other similar sensors providing information to a vehicle system, vehicle operator or external site. The sensors can provide information about the vehicle and its interior or exterior environment, about individual components, systems, vehicle occupants, subsystems, or about the roadway, ambient atmosphere, travel conditions and external objects.

The system can use one or more interrogators each having one or more antennas that transmit radio frequency energy to the sensors and receive modulated radio frequency signals from the sensors containing sensor and/or identification information. One interrogator can be used for sensing multiple switches or other devices. For example, an interrogator may transmit a chirp form of energy at 905 MHz to 925 MHz to a variety of sensors located within or in the vicinity of the vehicle. These sensors may be of the RFID electronic type or of the surface acoustic wave (SAW) type. In the electronic type, information can be returned immediately to the interrogator in the form of a modulated RF signal. In the case of SAW devices, the information can be returned after a delay. Naturally, one sensor can respond in both the electronic and SAW delayed modes.

When multiple sensors are interrogated using the same technology, the returned signals from the various sensors can

be time, code, space or frequency multiplexed. For example, for the case of the SAW technology, each sensor can be provided with a different delay. Alternately, each sensor can be designed to respond only to a single frequency or several frequencies. The radio frequency can be amplitude or frequency modulated. Space multiplexing can be achieved through the use of two or more antennas and correlating the received signals to isolate signals based on direction.

In many cases, the sensors will respond with an identification signal followed by or preceded by information relating to the sensed value, state and/or property. In the case of a SAW-based switch, for example, the returned signal may indicate that the switch is either on or off or, in some cases, an intermediate state can be provided signifying that a light should be dimmed, rather than or on or off, for example.

Great economies are achieved by using a single interrogator or even a small number of interrogators to interrogate many types of devices. For example, a single interrogator may monitor tire pressure and temperature, the weight of an occupying item of. the seat, the position of the seat and seatback, as well as a variety of switches controlling windows, door locks, seat position, etc. in a vehicle. Such an interrogator may use one or multiple antennas and when multiple antennas are used, may switch between the antennas depending on what is being monitored.

More particularly, the tire monitoring system of this invention actually comprises three separate systems corresponding to three stages of product evolution. Generation 1 is a tire valve cap that provides information as to the pressure within the tire as described below. Generation 2 requires the replacement of the tire valve stem, or the addition of a new stem-like device, with a new valve stem that also measures temperature and pressure within the tire or it may be a device that attaches to the vehicle wheel rim. Generation 3 is a product that is attached to the inside of the tire adjacent the tread and provides a measure of the diameter of the footprint between the tire and the road, the tire pressure and temperature, indications of tire wear and, in some cases, the coefficient of friction between the tire and the road.

Surface acoustic wave technology permits the measurement of many physical and chemical parameters without the requirement of local power or energy. Rather, the energy to run devices can be obtained from radio frequency electromagnetic waves. These waves excite an antenna that is coupled to the SAW device. Through various means, the properties of the acoustic waves on the surface of the SAW device are modified as a function of the variable to be measured. The SAW device belongs to the field of microelectromechanical systems (MEMS) and can be produced in high-volume at low cost.

For the generation **1** system, a valve cap contains a SAW material at the end of the valve cap, which may be polymer covered. This device senses the absolute pressure in the valve cap. Upon attaching the valve cap to the valve stem, a depressing member gradually depresses the valve permitting the air pressure inside the tire to communicate with a small volume inside the valve cap. As the valve cap is screwed onto the valve stem, a seal prevents the escape of air to the atmosphere. The SAW device is electrically connected to the valve cap, which is also electrically connected to the valve stem that acts as an antenna for transmitting and receiving radio frequency waves. An interrogator located within 20 feet of the tire periodically transmits radio waves that power the SAW device. The SAW device measures the absolute pressure in the valve cap that is equal to the pressure in the tire. U.S. Pat. Nos. 5,641,902, 5,819, 779 and 4,103,549 illustrate a valve cap pressure sensor where a visual output is provided. Other related prior art includes U.S. Pat. No. 4,545,246.

The generation **2** system permits the measurement of both the tire pressure and tire temperature. In this case, the tire valve stem is removed and replaced with a new tire valve stem that contains a SAW device attached at the bottom of the valve stem. This device actually contains two SAW devices, one for measuring temperature and the second for measuring pressure through a novel technology discussed below. This second generation device therefore permits the measurement of both the pressure and the temperature inside the tire. Alternately, this device can be mounted inside the tire, attached to the rim or attached to another suitable location. An external pressure sensor is mounted in the interrogator to measure the pressure of the atmosphere to compensate for altitude and/or barometric changes.

The generation **3** device contains a pressure and temperature sensor, as in the case of the generation **2** device, but additionally contains one or more accelerometers which measure at least one component of the acceleration of the vehicle tire tread adjacent the device. This acceleration varies in a known manner as the device travels in an approximate circle attached to the wheel. This device is capable of determining when the tread adjacent the device is in contact with road surface. It is also able to measure the coefficient of friction between the tire and the road surface. In this manner, it is capable of measuring the length of time that this tread portion is in contact with the road and thereby provides a measure of the diameter of the tire footprint on the road. A technical discussion of the operating principle of a tire inflation and load detector based on flat area detection follows:

When tires are inflated and not in contact with the ground, the internal pressure is balanced by the circumferential tension in the fibers of the shell. Static equilibrium demands that tension is equal to the radius of curvature multiplied by the difference between the internal and the external gas pressure. Tires support the weight of the automobile by changing the curvature of the part of the shell that touches the ground. The relation mentioned above is still valid. In the part of the shell that gets flattened, the radius of curvature increases while the tension in the tire structure stays the same. Therefore, the difference between the external and internal pressures becomes small to compensate for the growth of the radius. If the shell were perfectly flexible, the tire contact with the ground would develop into a flat spot with an area equal to the load divided by the pressure.

A tire operating at correct values of load and pressure has a precise signature in terms of variation of the radius of curvature in the loaded zone. More flattening indicates under-inflation or overloading, while less flattening indicates over-inflation or under-loading. Note that tire loading has essentially no effect on internal pressure.

From the above, one can conclude that monitoring the curvature of the tire as it rotates can provide a good indication of its operational state. A sensor mounted inside the tire at its largest diameter can accomplish this measurement. Preferably, the sensor would measure mechanical strain. However, a sensor measuring acceleration in any one axis could also serve the purpose.

In the case of the strain measurement, the sensor would indicate a constant strain as it spans the arc over which the tire is not in contact with the ground, and a pattern of increased stretch during the arc of close proximity with the ground. A simple ratio of the times of duration of these two states would provide a good indication of inflation, but more

complex algorithms could be employed, where the values and the shape of the period of increased strain are utilized.

In the case of acceleration measurement, the system would utilize the fact that the part of the tire in contact with the ground possesses zero velocity for a finite period of time, while the rest of the tire is accelerating and decelerating in a cyclic fashion. The resulting acceleration profiles in the circumferential axis or the radial axis present a characteristic near-zero portion, the length of which, when related to the rest of the rotation, is a result of the state of tire inflation.

As an indicator of tire health, the measurement of strain on the largest inside diameter of the tire is believed to be superior to the measurement of stress, such as inflation pressure, because, the tire could be deforming, as it ages or otherwise progresses toward failure, without any changes in inflation pressure. Radial strain could also be measured on the inside of the tire sidewall thus indicating the degree of flexure that the tire undergoes.

The accelerometer approach has the advantage of giving a signature from which a harmonic analysis of once-per-revolution disturbances could indicate developing problems such as hernias, flat spots, loss of part of the tread, sticking of foreign bodies to the tread, etc.

As a bonus, both of the above-mentioned sensors give clear once-per-revolution signals for each tire that could be used as inputs for speedometers, odometers, differential slip indicators, tire wear indicators, etc.

Tires can fail for a variety of reasons including low pressure, high temperature, delamination of the tread, excessive flexing of the sidewall, and wear (see, e.g., Summary Root Cause Analysis Bridgestone/Firestone, Inc." http://www.bridgestone-firestone.com/homeimgs/rootcause.htm, Printed March, 2001). Most tire failures can be predicted based on tire pressure alone and the TREAD Act thus addresses the monitoring of tire pressure. However, some failures, such as the Firestone tire failures, can result from substandard materials especially those that are in contact with a steel-reinforcing belt. If the rubber adjacent the steel belt begins to move relative to the belt, then heat will be generated and the temperature of the tire will rise until the tire fails catastrophically. This can happen even in properly inflated tires.

Finally, tires can fail due to excessive vehicle loading and excessive sidewall flexing even if the tire is properly inflated. This can happen if the vehicle is overloaded or if the wrong size tire has been mounted on the vehicle. In most cases, the tire temperature will rise as a result of this additional flexing, however, this is not always the case, and it may even occur too late. Therefore, the device which measures the diameter of the tire footprint on the road is a superior method of measuring excessive loading of the tire.

Generation **1** devices monitor pressure only while generation **2** devices also monitor the temperature and therefore will provide a warning of imminent tire failure more often than through monitoring pressure alone. Generation **3** devices will give an indication that the vehicle is overloaded before either a pressure or temperature monitoring system can respond. The generation **3** system can also be augmented to measure the vibration signature of the tire and thereby detect when a tire has worn to the point that the steel belt is contacting the road. In this manner, the generation **3** system also provides an indication of a worn out tire and, as will be discussed below, an indication of the road coefficient of friction.

Each of these devices communicates to an interrogator with pressure, temperature, and acceleration as appropriate. In none of these generational devices is a battery mounted within the vehicle tire required, although in some cases a generator can be used. In most cases, the SAW devices will optionally provide an identification number corresponding to the device to permit the interrogator to separate one tire from another.

Key advantages of the tire monitoring system disclosed herein over most of the currently known prior art are:

very small size and insignificant weight eliminating the need for wheel counterbalance,

cost competitive for tire monitoring only, significant cost advantage when systems are combined,

exceeds customers' price targets,

high update rate,

self-diagnostic,

automatic wheel identification,

no batteries required—powerless,

no wires required—wireless.

SAW devices have been used for sensing many parameters including devices for chemical sensing and materials characterization in both the gas and liquid phase. They also are used for measuring pressure, strain, temperature, acceleration, angular rate and other physical states of the environment.

The monitoring of temperature and or pressure of a tire can take place infrequently. It is adequate to check the pressure and temperature of vehicle tires once every ten seconds to once per minute. To utilize the centralized interrogator of this invention, the tire monitoring system would preferably use SAW technology and the device could be located in the valve stem, wheel, tire side wall, tire tread, or other appropriate location with access to the internal tire pressure of the tires. A preferred system is based on a SAW technology discussed above.

At periodic intervals, such as once every minute, the interrogator sends a radio frequency signal at a frequency such as 905 MHz to which the tire monitor sensors have been sensitized. When receiving this signal, the tire monitor sensors (of which there are five in a typical configuration) respond with a signal providing an optional identification number, temperature and pressure data. In one implementation, the interrogator would use multiple, typically two or four, antennas which are spaced apart. By comparing the time of the returned signals from the tires to the antennas, the location of each of the senders can be approximately determined. That is, the antennas can be so located that each tire is a different distance from each antenna and by comparing the return time of the signals sensed by the antennas, the location of each tire can be determined and associated with the returned information. If at least three antennas are used, then returns from adjacent vehicles can be eliminated.

An identification number can accompany each transmission from each tire sensor and can also be used to validate that the transmitting sensor is in fact located on the subject vehicle. In traffic situations, it is possible to obtain a signal from the tire of an adjacent vehicle. This would immediately show up as a return from more than five vehicle tires and the system would recognize that a fault had occurred. The sixth return can be easily eliminated, however, since it could contain an identification number that is different from those that have heretofore been returned frequently to the vehicle system or based on a comparison of the signals sensed by the different antennas. Thus, when the vehicle tire is changed or tires are rotated, the system will validate a particular return signal as originating from the tire-monitoring sensor located on the subject vehicle.

This same concept is also applicable for other vehicle-mounted sensors. This permits a plug and play scenario whereby sensors can be added to, changed, or removed from a vehicle and the interrogation system will automatically adjust. The system will know the type of sensor based on the identification number, frequency, delay and/or its location on the vehicle. For example, a tire monitor could have a different code in the identification number from a switch or weight-monitoring device. This also permits new kinds of sensors to be retroactively installed on a vehicle. If a totally new type of the sensor is mounted to the vehicle, the system software would have to be updated to recognize and know what to do with the information from the new sensor type. By this method, the configuration and quantity of sensing systems on a vehicle can be easily changed and the system interrogating these sensors need only be updated with software upgrades which could occur automatically over the Internet.

Preferred tire-monitoring sensors for use with this invention use the surface acoustic wave (SAW) technology. A radio frequency interrogating signal is sent to all of the tire gages simultaneously and the received signal at each tire gage is sensed using an antenna. The antenna is connected to the IDT transducer that converts the electrical wave to an acoustic wave that travels on the surface of a material such as lithium niobate, or other piezoelectric material such as zinc oxide, Langasite or the polymer polyvinylidene fluoride (PVDF). During its travel on the surface of the piezoelectric material, either the time delay, resonant frequency, amplitude, or phase of the signal (or even possibly combinations thereof) is modified based on the temperature and/or pressure in the tire. This modified wave is sensed by one or more IDT transducers and converted back to a radio frequency wave that is used to excite an antenna for re-broadcasting the wave back to interrogator. The interrogator receives the wave at a time delay after the original transmission that is determined by the geometry of the SAW transducer and decodes this signal to determine the temperature and/or pressure in the subject tire. By using slightly different geometries for each of the tire monitors, slightly different delays can be achieved and randomized so that the probability of two sensors having the same delay is small. The interrogator transfers the decoded information to a central processor that then determines whether the temperature and/or pressure of each of the tires exceed specifications. If so, a warning light can be displayed informing the vehicle driver of the condition. In some cases, this random delay is all that is required to separate the five tire signals and to identify which tires are on the vehicle and thus ignore responses from adjacent vehicles.

With an accelerometer mounted in the tire, as is the case for the generation **3** system, information is present to diagnose other tire problems. For example, when the steel belt wears through the rubber tread, it will make a distinctive noise and create a distinctive vibration when it contacts the pavement. This can be sensed by the SAW accelerometer. The interpretation of various such signals can be done using neural network technology. Similar systems are described more detail in U.S. Pat. No. 5,829,782, incorporated by reference herein. As the tread begins to separate from the tire as in the Bridgestone cases, a distinctive vibration is created which can also be sensed by a tire-mounted accelerometer.

As the tire rotates, stresses are created in the rubber tread surface between the center of the footprint and the edges. If the coefficient of friction on the pavement is low, these stresses can cause the shape of the footprint to change. The generation **3** system, which measures the circumferential length of the footprint, can therefore also be used to measure the friction coefficient between the tire and the pavement.

Similarly, the same or a different interrogator can be used to monitor various components of the vehicle's safety system including occupant position sensors, vehicle acceleration sensors, vehicle angular position, velocity and acceleration sensors, related to both frontal, side or rear impacts as well as rollover conditions. The interrogator could also be used in conjunction with other detection devices such as weight sensors, temperature sensors, accelerometers which are associated with various systems in the vehicle to enable such systems to be controlled or affected based on the measured state.

Some specific examples of the use of interrogators and responsive devices will now be described.

The antennas used for interrogating the vehicle tire pressure transducers will be located outside of the vehicle passenger compartment. For many other transducers to be sensed the antennas must be located at various positions within passenger compartment. This invention contemplates, therefore, a series of different antenna systems, which can be electronically switched by the interrogator circuitry. Alternately, in some cases, all of the antennas can be left connected and total transmitted power increased.

There are several applications for weight or load measuring devices in a vehicle including the vehicle suspension system and seat weight sensors for use with automobile safety systems. As reported in U.S. Pat. Nos. 4,096,740, 4,623,813, 5,585,571, 5,663,531, 5,821,425 and 5,910,647 and International Publication No. WO 00/65320(A1), all of which are incorporated by reference herein to the extent the disclosure of these publications is necessary, SAW devices are appropriate candidates for such weight measurement systems. In this case, the surface acoustic way on the lithium niobate, or other piezoelectric material, is modified in delay time, resonant frequency, amplitude and/or phase based on strain of the member upon which the SAW device is mounted. For example, the conventional bolt that is typically used to connect the passenger seat to the. seat adjustment slide mechanism can be replaced with a stud which is threaded on both ends. A SAW strain device is mounted to the center unthreaded section of the stud and the stud is attached to both the seat and the slide mechanism using appropriate threaded nuts. Based on the particular geometry of the SAW device used, the stud can result in as little as a 3 mm upward displacement of the seat compared to a normal bolt mounting system. No wires are required to attach the SAW device to the stud. The interrogator transmits a radio frequency pulse at, for example, 925 MHz that excites antenna on the SAW strain measuring system. After a delay caused by the time required for the wave to travel the length of the SAW device, a modified wave is re-transmitted to the interrogator providing an indication of the strain of the stud with the weight of an object occupying the seat corresponding to the strain. For a seat that is normally bolted to the slide mechanism with four bolts, at least four SAW strain sensors would be used. Since the individual SAW devices are very small, multiple devices can be placed on a stud to provide multiple redundant measurements, or permit bending strains to be determined, and/or to permit the stud to be arbitrarily located with at least one SAW device always within direct view of the interrogator antenna. In some cases, the bolt or stud will be made on non-conductive material to limit the blockage of the RF signal. In other cases, it will be insulated from the slide (mechanism) and used as an antenna.

If two longitudinally spaced apart antennas are used to receive the SAW transmissions from the seat weight sensors,

one antenna in front of the seat and the other behind the seat, then the position of the seat can be determined eliminating the need for current seat position sensors. A similar system can be used for other seat and seatback position measurements.

For strain gage weight sensing, the frequency of interrogation would be considerably higher than that of the tire monitor, for example. However, if the seat is unoccupied then the frequency of interrogation can be substantially reduced. For an occupied seat, information as to the identity and/or category and position of an occupying item of the seat can be obtained through the multiple weight sensors described. For this reason, and due to the fact that during the pre-crash event the position of an occupying item of the seat may be changing rapidly, interrogations as frequently as once every 10 milliseconds can be desirable. This would also enable a distribution of the weight being applied to the seat to be obtained which provides an estimation of the position of the object occupying the seat. Using pattern recognition technology, e.g., a trained neural network, sensor fusion, fuzzy logic, etc., the identification of the object can be ascertained based on the determined weight and/or determined weight distribution.

There are many other methods by which SAW devices can be used to determine the weight and/or weight distribution of an occupying item other than the method described above and all such uses of SAW strain sensors for determining the weight and weight distribution of an occupant are contemplated. For example, SAW devices with appropriate straps can be used to measure the deflection of the seat cushion top or bottom caused by an occupying item, or if placed on the seat belts, the load on the belts can determined wirelessly and powerlessly. Geometries similar to those disclosed in U.S. Pat. No. 6,242,701 (which discloses multiple strain gage geometries, the entire disclosure of this patent is incorporated by reference herein to the extent the disclosure is necessary) using SAW strain-measuring devices can also be constructed, e.g., any of the multiple strain gage geometries shown therein.

Although a preferred method for using the invention is to interrogate each of the SAW devices using wireless means, in some cases it may be desirable to supply power to and/or obtain information from one or more of the devices using wires. As such, the wires would be an optional feature.

One advantage of the weight sensors of this invention along with the geometries disclosed in the '701 patent and herein below, is that in addition to the axial stress in the seat support, the bending moments in the structure can be readily determined. For example, if a seat is supported by four "legs", it is possible to determine the state of stress, assuming that axial twisting can be ignored, using four strain gages on each leg support for a total of 16 such gages. If the seat is supported by three legs, then this can be reduced to 12. Naturally, a three-legged support is preferable than four since with four, the seat support is over-determined severely complicating the determination of the stress caused by an object on the seat. Even with three supports, stresses can be introduced depending on the nature of the support at the seat rails or other floor-mounted supporting structure. If simple supports are used that do not introduce bending moments into the structure, then the number of gages per seat can be reduced to three providing a good model of the seat structure is available. Unfortunately, this is usually not the case and most seats have four supports and the attachments to the vehicle not only introduce bending moments into the structure but these moments vary from one position to another and with temperature. The SAW strain gages of this invention lend themselves to the placement of multiple gages onto each support as needed to approximately determine the state of stress and thus the weight of the occupant depending on the particular vehicle application. Furthermore, the wireless nature of these gages greatly simplifies the placement of such gages at those locations that are most appropriate.

One additional point should be mentioned. In many cases, the determination of the weight of an occupant from the static strain gage readings yields inaccurate results due to the indeterminate stress state in the support structure. However, the dynamic stresses to a first order are independent of the residual stress state. Thus, the change in stress that occurs as a vehicle travels down a roadway caused by dips in the roadway can provide an accurate measurement of the weight of an object in a seat. This is especially true if an accelerometer is used to measure the vertical excitation provided to the seat.

Some vehicle models provide load leveling and ride control functions that depend on the magnitude and distribution of load carried by the vehicle suspension. Frequently, wire strain gage technology is used for these functions. That is, the wire strain gages are used to sense the load and/or load distribution of the vehicle on the vehicle suspension system. Such strain gages can be advantageously replaced with strain gages based on SAW technology with the significant advantages in terms of cost, wireless monitoring, dynamic range, and signal level. In addition, SAW strain gage systems can be significantly more accurate than wire strain gage systems.

A strain detector in accordance with this invention can convert mechanical strain to variations in electrical signal frequency with a large dynamic range and high accuracy even for very small displacements. The frequency variation is produced through use of a surface acoustic wave delay line as the frequency control element of an oscillator. A surface acoustic wave delay line comprises a transducer deposited on a piezoelectric material such as quartz or lithium niobate which is disposed so as to be deformed by strain in the member which is to be monitored. Deformation of the piezoelectric substrate changes the frequency control characteristics of the surface acoustic wave delay line, thereby changing the frequency of the oscillator. Consequently, the oscillator frequency change is a measure of the strain in the member being monitored and thus the weight applied to the seat. A SAW strain transducer is capable of a degree of accuracy substantially greater than that of a conventional resistive strain gage.

Other applications of weight measuring systems for an automobile include measuring the weight of the fuel tank or other containers of fluid to determine quantity of fluid contained therein.

One problem with SAW devices is that if they are designed to operate at the GHz frequency, the feature sizes become exceeding small and the devices are difficult to manufacture. On the other hand, if the frequencies are considerably lower, for example, in the tens of megahertz range, then the antenna sizes become excessive. It is also more difficult to obtain antenna gain at the lower frequencies. This is also related to antenna size. One method of solving this problem is to transmit an interrogation signal in the many GHz range which is modulated at the hundred MHz range. At the SAW transducer, the transducer is tuned to the modulated frequency. Using a nonlinear device such as a Shocky diode, the modified signal can be mixed with the incoming high frequency signal and re-transmitted through the same antenna. For this case, the interrogator could continuously broadcast the carrier frequency.